HANDBOOK

OF

COST DATA

FOR

CONTRACTORS AND ENGINEERS

NET BOOK—This Book is supplied to the trade on terms which do not admit of discount.

THE MYRON C. CLARK PUBLISHING CO.

UCTION
OR

Society of Engineering Contractors, Member Am
Institute of Mining Engineers, Etc.

SECOND EDITION

CHICAGO AND NEW YORK

THE MYRON C. CLARK PUBLISHING CO.

1910

WESTERN NEWSPAPER UNION PRINT,
CHICAGO

PREFACE TO SECOND EDITION

The first edition of this work contained the equivalent of about 250,000 words, while this edition contains more than a million. Its four-fold growth has been due not only to the filling of many gaps that formerly existed, but to the addition of certain kinds of cost data that interest engineers only. In writing the first edition, I had primarily in mind the contractor, whose concern is to know the most economical method of construction and the unit costs in every detail. While every engineer should, and many do, take as keen an interest as the contractor in itemized unit costs, all engineers are called upon, at one time or another, to give approximate preliminary estimates of costs, and these must often be furnished before the structure has been designed. For example, a hydraulic engineer may be asked the probable cost of a filter plant for a city consuming a given amount of water. He should be able to state the cost of sand filter beds per acre, covered or uncovered, and the annual cost of operation per million gallons filtered. To illustrate again: A railway engineer finds that a high steel viaduct may be needed to cross a valley. He desires a rational formula by which the approximate weight of steel in such a viaduct can be computed, knowing the profile area. Or, if he plans a high timber trestle, he wants a method of approximating the number of feet board measure and the pounds of iron it will require.

In brief, the engineer needs frequently to ascertain the *number* of units in a structure of a given class and size, as well as the *unit costs;* whereas the contractor is usually satisfied with data giving the itemized unit costs under stated conditions. I have tried to supply both wants in this edition.

During the last four years I have continued accumulating data on methods and costs, a large part of which have been published in *Engineering-Contracting.* When I began to make these data a feature of *Engineering-Contracting,* I received several letters expressing the hope that I should be able to continue the work of publishing such cost data, but at the same time voicing a fear that the good material would soon be exhausted. So long as men remain possessed of inventive faculties and of genius for organization, we need never fear that new and valuable cost data will be unobtainable. Management engineering is an infant science, and we shall see astonishing changes in methods of doing work, in machines used, and consequently in unit costs.

This comparatively new study of engineering costs has not only

had a pronounced effect upon methods of construction, but has already begun to work a change in designs of engineering structures. Specifications drawn by engineers who are ignorant of the items of actual unit costs are often absurd in their requirements. Hence, as a knowledge of costs spreads, we may confidently expect radical changes in designs and in specifications. These changes will result in entirely new cost data, so that a dearth of this sort of information is not to be expected from now on.

I wish to acknowledge my indebtedness to the files of the following periodicals and society transactions:

Engineering-Contracting, Engineering News, Engineering Record, Railway Age-Gazette, Electric Railway Journal, Municipal Engineering Magazine, Municipal Journal and Engineer, Good Roads Magazine, Engineering Magazine, American Society of Civil Engineers, Western Society of Engineers, Association of Engineering Societies, Canadian Society of Civil Engineers, Illinois Society of Engineers, Engineers' Society of Western Pennsylvania, Engineers' Club of Philadelphia, New England Water Works Association, American Water Works Association, American Railway Engineering and Maintenance of Way Association, American Association of Railway Superintendents of Bridges and Buildings, and the Institution of Civil Engineers.

HALBERT P. GILLETTE.

New York, March 14, 1910.

PREFACE TO FIRST EDITION.

Four years ago I announced in my little book, "Economics of Road Construction," that I had in preparation a handbook of cost data for engineers and contractors. At that time this handbook had been under way for eight years, and it seemed nearly ready for publication; but other duties prevented a speedy finishing of the task. The delay, however, has been fortunate in that I have added very much to my knowledge of the general subject. In the meantime, two books have grown out of the original manuscript, namely, my books on earthwork and on rock excavation. The writing of these two books has better fitted me for the writing of this book, and has put me in touch with many engineers and contractors who have generously furnished additional cost data.

So far as I know, this is the first book on engineering cost data ever published. There are "price books" written for house builders, but they are essentially what their name implies—books on prices of materials and contract prices. This book differs from all such works, aside from the fact that it covers the whole field of civil engineering, in that it is a book in which *costs* are analyzed and discussed. A contract *price* is one thing, a contract *cost* is an entirely different thing, in spite of the common confusion of these terms. In order fully to understand any analysis of unit costs it is necessary to have a detailed description of the methods used in construction and operation. Hence, although itemized cost data

occupy many scores of pages in this book, there are many more scores of pages devoted to descriptions of how the work was done, the organization of the forces, and the machines used. The records, in all cases, are actual records taken from every available source of published information, from personal letters sent by engineers and contractors and from my own records.

It is often said that cost data are of no value to an inexperienced man. Generally the men who make such statements are themselves possessed of few records of cost, or use this argument as an excuse for not making public such records as they do possess. The very secretiveness of men having cost data which they refuse to make public, nullifies their statement that such data can be of no use to others.

We also hear it argued that conditions vary so widely that grave errors occur when an attempt is made to apply published cost data. Those who have not been trained to study the conditions affecting costs are likely to make serious blunders in any case; but, if this book is in even a slight degree what it aims to be, it will be of greatest benefit to just such men; for it will indicate to them how to analyze costs and how to study methods of performing work economically.

Many of the erroneous ideas about the value of cost recording arise from a confusion of the term cost with the term price. This is not a handbook of prices, although many prices are given. I could have filled ten volumes with prices, and with summaries of costs written by engineers who have failed to state rates of wages and conditions under which the work was performed. But, a short time after publication, all such matter is hardly worth the ink that it is printed with, since wages and prices are subject to constant change.

The attention of contractors is called to the first part of the book in which systems of cost keeping are described. I have outlined what I believe to be some of the best systems of cost keeping. Samples of other record cards and methods than my own are shown; for my purpose has been to elucidate principles, rather than to exploit pet theories as to business management and accounting.

HALBERT P. GILLETTE.

New York, Sept. 1, 1905.

NOTICE TO AUTHORS

Authors of text books have quoted freely from the first edition of this book, often without securing permission. While we follow a liberal policy in the matter of permitting quotations, both from our books and from the pages of *Engineering-Contracting* (which is also a copyrighted publication), we expect authors to communicate with us, indicating what they desire to quote.

THE MYRON C. CLARK PUBLISHING CO.

CONTENTS.

HANDBOOK OF COST DATA.

INTRODUCTION.

John Stuart Mill has said: "Without any formal instruction, the language in which we grow up teaches us all the common philosophy of the age."

If it is even partially true that general knowledge is affected by words and expressions in common use, it is certainly undeniable that formal definitions of words have a much greater effect upon the scope of mental vision. When the formal definition is of a word that denotes a profession, the far-reaching consequence can hardly be estimated. No definition of any profession has had wider circulatino and more general acceptance than the old one formulated by Tredgold and adopted in its infancy by the Institution of Civil Engineers:

"Engineering is the art of directing the great sources of power in nature for the use and convenience of man."

Note the entire absence of any reference to economics in this definition. Engineering, when Tredgold lived, was in the stage of development when the common problem before an engineer was not whether a thing could be done economically but whether it could be done at all. Then followed the reign of the mathematicians who took up engineering, just as in previous years mathematicians had seized upon astronomy as a delightful science in which to exercise their talents. But among mathematicians there has always been a liking for the ancient toast: "Here's to pure mathematics. May it never be of any use to anybody." So it was naturally to be expected that anything so "commercial" as saving money should not have appealed very strongly to the mathematicians who had taken up engineering. Nor did it. Nor has there been an entire escape to this day from the bondage of that early type of engineering. Tredgold's definition really fails to *define*, or limit, the word engineering. Under his definition any man who directs any of the great forces of nature for the use of men is an engineer. The farmer who utilizes that enormous force—the sun's heat—for the "use and convenience of man," is an engineer. So, too, is the sailor who directs that other vast force, the wind, to the driving of his ship. In fact, there is no limit to the classes of men who fall within the literal wording of this definition. It is, therefore, a very unsatisfactory definition because of its vagueness. However, I object to it not so much upon the ground that it includes too much as upon the ground that it fails to include what it should, namely the fundamental function of the modern engineer, which is to solve problems in economic production.

I recall with what keen interest I first read that now historic work, Wellington's "Economic Theory of the Location of Railways." I was particularly struck with this opening paragraph:

"It would be well if engineering were less generally thought of, and even defined, as the art of constructing. In a certain important sense it is rather the art of not constructing; or, to define it rudely but not inaptly, it is the art of doing that well with one dollar, which any bungler can do with two after a fashion."

Wellington made no attempt to give a complete definition of engineering, but he certainly was among the first, if not the first, to indicate the inherent weakness of such definitions as that of Tredgold. Wellington has it to his lasting credit that he made a valiant effort to reducé railway location to an economic science. That he made many errors, or that he was not always even logical, detracts little from his eminent position as one of the greatest teachers of what engineering really is.

Engineering is the conscious application of science to the problems of economic production.

Under this definition, which may ultimately be regarded as too broad, I aim to include that part of engineering which relates to the scientific management of men, and the scientific development of methods of construction and operation, as well as the design of the most economic structures and machines for a given service. The word art does appear in the definition, for it is obvious that in the application of scientific principles in the solution of any problem, what may be termed "art" must be exercised if the greatest success is to follow. Natural aptitude, practice and experience are the qualifications of every man who is a real artist in the execution of a task. These are the qualities that cannot be imparted by teaching.

Since engineering in the modern sense of the term consists in solving problems in economic construction and operation, it should be apparent to all that cost data are of primary importance to every engineer. For, just as data on the resistance of materials to stress are essential in economizing the materials in a bridge, a building, or a machine, so data as to unit costs of construction, operation and maintenance are vitally valuable to every engineer who attempts to be an engineer in the modern meaning of the term.

To my great surprise, the first edition of this Handbook of Cost Data was scarcely off the press before editorials and articles began to appear in certain engineering periodicals belittling the value of cost data. I had taken particular care, as I had thought, in pointing out the difference between the *price* of anything and its actual *cost*. Yet it was said by writers that prices fluctuated so rapidly that cost records are of no particular value except for very short periods of time. Lest this confusion of terms shall continue to mislead, I purpose briefly indicating again their meaning.

The *price* of any article is the money paid for it by a consumer. It is the *cost* to the consumer, and in that sense of the word I use the term cost occasionally in this book, but never in such a way as to cause confusion, the meaning being always obvious by the context.

The *cost* of any article is money paid by the producer for materials, supplies, labor, etc., necessary in its production. His profit he difference between this cost and the price he receives.

Clearly, then, if we give the number of hours or days of labor of a stated class required to produce a unit of product, we have given its *cost* in terms that may be of permanent value, so long as the same methods of doing the work remain in vogue. In brief, we have given the cost in terms of the day's output of a man, and this is by no means a quantity subject to erratic fluctuations. Indeed, under equally good management such costs are often astonishingly stable. If anyone doubts this statement, I ask him to compare the data in my little book "The Economics of Road Construction," written in 1900, with corresponding data in Aitken's "Road Making and Maintenance," published a few weeks after I had turned over my manuscript to my publishers. Aitken wrote of English methods and cost of building macadam roads. He used American rock drills and English steam rollers. I used machines and tools almost identical, and our respective unit costs were, on most items, nearly identical when reduced to the same unit rates of wages.

It is the veriest nonsense to attribute to *cost data* an ephemeral or purely local value, because *prices* vary with supply and demand, or because local conditions differ more or less. *Prices* have nothing to do with the matter at all in making proper comparisons of cost data, since, if quantities of materials and quantities of labor are stated, the substitution of standard prices for materials and of standard wages for labor is a mere matter of common sense and the multiplication table.

Fallacies, however, die with cat-like protraction. Hence, when the first published objections to the real and general value of published cost data were seemingly killed, I found them struggling to life again. In a recent paper before the American Society of Civil Engineers it was urged that, while cost data may be valuable they are of no great value except to the man who gathered the data! This same fallacy has also been repeated in two engineering journals, both editorially and in contributed articles.

Were it not for the sources of these errors I should ignore them. But they seem to merit at least a passing notice.

Cost data differ from other engineering data in no essential respect, except, perhaps, in this: Workmen who are underpaid, or poorly managed, or arrogant because of a false feeling of independence, may not do a full day's work. When this is so, unit costs are necessarily high if measured in terms of the man-day. This condition, however, can be recorded, and, in fact, it records itself if we have other data for comparison.

Cost data can be so reduced to items and accompanied by statements of conditions as to be of as much value to engineers and contractors as any other kind of data. Data of strengths, for example, are very misleading if unaccompanied by descriptions of the size of test pieces, chemical composition, and many other factors, which are entirely analogous to the "local conditions" that cause variations in cost data. By curious coincidence, one of the engineers who has most severely criticized cost data is the author of a 250-page book giving nothing but records of strength and elasticity tests of Portland cement and concrete. If cost data were subject to

a tenth of the variation found in these cement strengths, well might we dispair of reducing the subject of cost estimating to a science.

This last expression leads me to the real heart of the subject of this book, and the heart is not cost estimating—at least it is not that per se. Important as the matter of *estimating* costs often is, the overshadowing value of cost data as a guide in *reducing* costs will be apparent to every engineer, contractor or manufacturer who has been long engaged as a producer of things for sale.

Comparison of unit costs is the only scientific criterion by which to judge the economic merit of a structure, a machine, or a method of doing work.

This fact is so self-evident that its meaning needs but to be understood to find full acceptance by everyone of open mind and unclouded brain. Yet, failure to formulate this law has led to some of the most astounding methods of designing and of selecting engineering structures. For example, in nearly every American treatise on highway construction will be found a method which the highway engineer is supposed to follow in selecting the type of pavement for a given street. The method consists in assigning percentages to each of the qualities that pavement has, as follows:

	Per cent.
Low first cost	15
Low cost of maintenance	20
Ease of traction	10
Good foothold	5
Ease of cleaning	10
Noiseless	15
Healthfulness	10
Free from mud and dust	10
Comfortable to use	3
Non-absorbent of heat	2
Total	100

If a pavement possesses any one of these qualities to perfection, the full percentage assigned to each quality is credited to that pavement. The pavement showing the highest total percentage is the one to be selected. This looks somewhat scientific, with its tabulation of ratios, but it is not even scientific guesswork. As well choose a suit of clothes by assigning 10% to the buttons, 50% to the cloth and 40% to the style. Pseudo-science of this sort would never have gotten into the pages of engineering textbooks had there been a clear and complete definition of engineering in the minds of the authors. I need not stop to point out the scientific method of designing or selecting a pavement, for that will follow as a corollary to the criterion for economic design, given later.

I wish here to emphasize the fact that no paper read before an engineering society, nor any article printed in an engineering periodical on the design of a machine or structure, is ideal in its character unless it is accompanied by cost data. I would not be understood, however, as saying that the absence of cost data makes an article of this sort worthless. Far from it. But the absence of cost data weakens the article, for, without the accurate criterion that

cost data—and cost data only—furnish, a precise judgment as to the economic merit of the machine or structure is impossible.

The same holds true of a method of doing work, and that is why I have chosen to link the words *methods and cost* in the subtitles of several of my books on construction.

Often a cost is so nearly a function of the amounts of material required in a structure or machine that the dollar's mark need not appear at all—simply the quantities of each kind of material per unit of product. This is particularly true of steel bridges. Perhaps this fact accounts, in a measure, for the indifference of some bridge engineers to the importance of cost data. They fail to see that in other lines of engineering the quantity of materials is not always a function of the cost. But even in bridge work it is fatal to true economy to have eyes only for the amount of materials required for the structure. A study of the section on bridgework in this book will make evident this fact.

In the operation of plants of given capacity and of stated class, cost data are invaluable as a criterion of the efficiency of machines, of men and of management. Unfortunately, most writers on this branch of cost data have hitherto recorded only the dollars and cents cost of the various items of operating expense. We often find, for example, that the item of fuel has cost so and so many dollars per year, or per horsepower-year, without a word as to the number of tons of fuel and the price per ton. We read that the wages of operation totaled so and so, without finding a detailed statement of the organization of the operating crew and the rates of wages paid to each class of men. We are told that repairs cost so and so many dollars per year, but the first cost of the plant is omitted, so that we are unable to reduce the repairs to a percentage of the first cost; nor is the age of the plant stated, so that, even if its first cost were given, we should be in doubt as to whether the plant had been long enough in use to reach a stage of average repairs.

All such omissions, however, are not a fair indictment of cost data. A just criticism of imperfect cost data, or of imperfect records of the conditions to which they apply, is quite a different thing from an attempt to belittle the value of all cost data "except to the man who gathered them." Were it literally true that cost data are of worth only to the man who has seen the local conditions, we should, indeed, be in a sorry state. The civil engineer engaged in locating a railway, having never personally gathered any railway operating costs, would be compelled to ignore all such cost data in solving the various problems of location.

Where, indeed, will this nonsense lead us, if we will be lead by it? Obviously to a point where no engineer will dare use any cost data at all, except his own meager pickings from his own little crab-apple tree of experience.

The great and steadily greater growing efficiency of engineers is due to their use of all kinds of data—cost data included—gathered by all kinds of engineers.

I expect to live to see the day when a knowledge of cost data and how to use them will be generally regarded by engineers as of

greater importance even than a similar knowledge of the physical properties of materials.

Finally, in this foreword, I would impress upon young engineers the importance of examining the definitions of all terms with care. I have indicated how a confusion as to the words price and cost has often resulted in speaking of *costs* as not being stable when what was meant was the instability of *prices*. I have indicated how an ancient definition of the word engineering may have been a factor in leading many engineering educators to follow the old precedent too closely for the good of the students who, upon graduation, must change their conceptions of what are the most common and the most important engineering problems.

In the following pages will be found a striking illustration of the errors that some engineers have made through confusing the words depreciation and repairs.

I commend to all engineers the careful study of Mill's "System of Logic," and particularly his chapters on Definition and on Fallacies of Confusion.

SECTION I.

PRINCIPLES OF ENGINEERING, ECONOMICS AND COST KEEPING.

Definitions.—Not only for the benefit of younger men and of foreign engineers does it seem wise to give the following definitions, but because there is not at present an entire uniformity among American engineers as regards the meaning of some of the terms.

Amount.—The principal plus accumulated interest.

Amortization.—The extinction of a debt by means of a sinking fund, or the provision for the redemption of an investment in a plant, a mine, or the like, by means of a sinking fund.

Betterment.—An improvement. In railway parlance, any expenditure for "addition and improvement."

Bid.—To submit a contract price; the bidding price being the tender.

Book Value.—The value of a plant as recorded in the accounting books of a company. Often it represents the price paid for the plant and the franchise under which it operates. Often it is the estimated depreciated value.

Bonus.—A payment to a workman in addition to his hourly, daily or weekly wage. The bonus system is a modified piece rate system by which a workman receives a stipulated price (= bonus) for each unit of work done in excess of a stipulated minimum, in addition to his regular wage.

Capitalize.—To divide an annual operating or maintenance expense by a rate of interest. The quotient thus obtained is called the capitalized cost of the annual expense.

Contingencies.—Unforeseen expenses.

Cost.—The actual cost of materials, supplies, labor, etc., required to produce an article or to perform a service. Also frequently used to denote the *price* that a purchaser has paid.

Cost of Reproduction.—The present cost of a plant, or plant unit, regarded as reproduced new at present prices.

Data.—Facts, and particularly those that can be numerically expressed. The word is the plural of datum, but so many writers use the word data with a singular verb that it seems likely to follow the precedent of such words as news. In Shakespeare's time,

news was used only in the plural; now it is always singular.

Demurrage.—The amount paid a railway company for holding a car beyond a certain time.

Depreciation.—Decrease in value. It is preferable not to use the word to denote "repairs and renewals," but to use "maintenance" for that purpose. Depreciation is best used only to denote annual expense for the entire *renewal* of a plant unit. It will then be either the amount annually placed in a sinking fund, or the amount paid out of current income for plant renewals, renewals, in the latter case, being regarded merely as repairs on a larger scale. Three formulas for depreciation are given in the following pages: (1) The straight line formula; (2) Sinking fund formula; (3) Unit cost of production formula.

Equipment.—In railway parlance, rolling stock, including locomotives and cars. Unfortunately the term has been latterly used to include the power stations and electrical plant of electric railways. It will be well to discontinue the use of equipment in any sense but as relating to rolling stock.

Fixed Charges.—Often used to denote only the interest charges on the funded debt of plant, but more often used to include all expenses that go on whether a plant is in operation or not.

Funded Debt.—The bonds of a railway.

Going Concern Value.—The amount of money expended in building up a business, or the measure of increased value possessed by an old business over a similar business just started with a new plant.

Maintenance Expense.—The annual expense for repairs and entire renewals of plant units.

Materials.—The substances actually entering the construction of a machine or structure, as distinguished from *supplies.* This distinction is not always made, but is desirable.

Obsolescence.—The state of going out of use through becoming obsolete.

Operating Expense.—In railway parlance this includes the expense of operating and maintaining a railway plant. The *operating ratio* is the ratio of operating expense to gross earnings. In manufacturing and contracting parlance, operating expense of'en does not include maintenance, which is classed as a distinct item, and includes repairs and renewals.

Original Cost.—The actual original cost of a plant, including additions and improvements, but not including profits resulting from the sale of the completed plant.

rhead Charges.—Generally used to include only office expenses eneral miscellaneous expenses, the latter being so general that can not be charged either against the office or field or shop, re incurred in the maintenance of the business in general.

ce Rate.—A rate paid to a workman for each unit, or piece, of performed. When an increasing piece rate is paid as the num- f units of output increases, it is called a *differential piece rate.*

nt.—The physical property used in production, including ma- s, land, etc.

sent Value.—Depreciated value.

ice.—The market price, as distinguished from the actual *cost* oduce a structure, machine, or the like.

ncipal.—The original sum upon which interest is calculated.

ciprocal.—The reciprocal of a number is 1 divided by that num- The reciprocal of 20 is 1/20, or 0.05, or 5%.

vage Value.—The price that is realized from the sale of a de- ated machine or structure.

op Repairs.—The repairs that a machine receives in a shop, as nguished from repairs received in the field.

king Fund.—A fund established for the ultimate payment of bt, or for the redemption of an investment in a plant, mine, etc. nnual deposit is ordinarily made in the fund, and the fund in- es by these deposits and by compound interest.

pplies.—All items of material necessary to carry on work, but h are rapidly destroyed in the process of production; e. g., coal, ope, hose, etc. See Materials, above defined.

nder.—To bid.

balanced Bid.—A bid in which certain unit prices are above a price and other unit prices are below a fair price.

it Cost.—The total cost of producing a unit, such as a cubic of concrete.

it interest cost is the total annual interest on a plant invest- divided by the total number of units of product. A *plant unit* ingle machine, or a single structure.

lue.—The worth of a thing. This may be its market price, or it be a sum arrived at by estimating depreciated value, or it may sum determined by capitalizing annual net earnings, or it may sum determined by capitalizing annual saving in operating or tenance expense. See Book Value, above.

npound Interest Tables.—These are ordinarily given in two , as in Tables I and II.

Let A = amount, or accumulation of $1 and interest during n years.
r = rate of interest, payments made at the end of each year.
n = number of years.

Then (1) $A = (1 + r)^n$.

Table I is calculated by formula (1). If the principal is $20, simply multiply the amount found in Table I by 20; and in like manner for any other principal. It is convenient to bear in mind that money at compound interest doubles itself in approximately the number of years obtained by dividing 72 by the rate of interest. This is not strictly accurate, as may be seen from Table I, but, for the rough and ready estimates that an engineer is often called upon to make, it will generally suffice.

Table I is, for many engineering purposes, less convenient than Table II, which is also a compound interest table. The amounts given in Table II are the reciprocals of the corresponding amounts in Table I. Table II is useful in determining the *present value or present justifiable expenditure to secure a return of $1 at the end of any number of years.*

To illustrate the use of Table II, suppose it to be probable that the traffic of a projected change of railway line will be double in ten years what it is at present.

Suppose that present operating expenses can be reduced by an improved location of the line, and that the capitalized value of the saving in present operating expenses is $1. Then there is certainly economic warrant for spending that $1, but how much may be now spent to save the other $1 in operating expenses which will be effected by this improvement when traffic shall have doubled 10 years hence?

Table II gives the answer; for if money can be borrowed at 5%, the table shows that $0.614 may be spent now to secure a betterment which will yield a capitalized value of $1 in reduced operating expenses 10 years hence.

Therefore the total present justified expenditure becomes $1.614, of which $1 is the capitalized saving in present operating expense and $0.614 the capitalized saving in future operating expense when the traffic shall have doubled.

As Wellington points out, this is the maximum justifiable expenditure to effect a future saving in operating expense; for, unless there is assurance that earnings will be sufficient to pay the interest upon the increased obligations, danger exists of financial embarrassment which may result disastrously to the railway owners.

Table I.—Compound Interest Table.

Amount of $1 Placed at Compound Interest for a Term of Years.

Years.	3 per cent.	3½ per cent.	4 per cent.	5 per cent.	6 per cent.	8 per cent.	10 per cent.
1............	1.03	1.03	1.04	1.05	1.06	1.08	1.10
2............	1.06	1.07	1.08	1.10	1.12	1.17	1.21
3............	1.09	1.11	1.12	1.16	1.19	1.26	1.33
4............	1.13	1.15	1.17	1.22	1.26	1.36	1.46
5............	1.16	1.19	1.22	1.28	1.34	1.47	1.61
6............	1.19	1.23	1.27	1.34	1.42	1.59	1.77
7............	1.23	1.27	1.32	1.41	1.50	1.71	1.95
8............	1.27	1.32	1.37	1.48	1.59	1.85	2.14
9............	1.30	1.36	1.42	1.55	1.69	2.00	2.36
10............	1.34	1.41	1.48	1.63	1.79	2.16	2.59
11............	1.38	1.46	1.54	1.71	1.89	2.33	2.85
12............	1.43	1.51	1.60	1.80	2.01	2.52	3.14
13............	1.47	1.56	1.67	1.89	2.13	2.72	3.45
14............	1.51	1.62	1.73	1.98	2.26	2.94	3.79
15............	1.56	1.68	1.80	2.08	2.40	3.17	4.17
16............	1.60	1.73	1.87	2.18	2.54	3.43	4.60
17............	1.65	1.79	1.95	2.29	2.69	3.70	5.05
18............	1.70	1.86	2.03	2.41	2.85	4.00	5.55
19............	1.75	1.92	2.11	2.53	3.03	4.31	6.11
20............	1.81	1.99	2.19	2.65	3.21	4.66	6.72
21............	1.86	2.06	2.28	2.79	3.40	5.03	7.39
22............	1.92	2.13	2.37	2.93	3.60	5.44	8.13
23............	1.97	2.21	2.46	3.07	3.82	5.87	8.94
24............	2.03	2.28	2.56	3.23	4.05	6.34	9.83
25............	2.09	2.36	2.67	3.39	4.29	6.85	10.81
26............	2.16	2.45	2.77	3.56	4.55	7.39	11.90
27............	2.22	2.53	2.88	3.73	4.82	7.99	13.08
28............	2.29	2.62	3.00	3.92	5.11	8.62	14.39
29............	2.36	2.71	3.12	4.12	5.42	9.31	15.83
30............	2.43	2.81	3.24	4.32	5.74	10.06	17.41
31............	2.50	2.91	3.37	4.54	6.09	10.86	19.15
32............	2.58	3.01	3.51	4.76	6.45	11.74	21.06
33............	2.65	3.11	3.65	5.00	6.84	12.67	23.17
34............	2.73	3.22	3.79	5.25	7.25	13.69	25.48
35............	2.81	3.33	3.95	5.52	7.68	14.78	28.03
36............	2.90	3.45	4.10	5.79	8.15	15.96	30.83
37............	2.99	3.57	4.27	6.08	8.63	17.24	33.91
38............	3.07	3.70	4.44	6.39	9.15	18.62	37.30
39............	3.17	3.83	4.62	6.70	9.70	20.11	41.02
40............	3.26	3.96	4.80	7.04	10.28	21.72	45.12
42............	3.46	4.24	5.19	7.76	11.56	25.33	54.59
44............	3.67	4.54	5.62	8.56	12.98	29.54	66.04
46............	3.90	4.87	6.07	9.43	14.59	34.46	79.90
48............	4.13	5.21	6.57	10.40	16.39	40.19	96.67
50............	4.38	5.58	7.11	11.47	18.42	46.88	117.00

TABLE II.—COMPOUND INTEREST TABLE.

Giving Sums Which at Compound Interest Will Amount to $1 in a Given Number of Years.

With Interest at—

Years.	3 per cent.	4 per cent.	5 per cent.	6 per cent.	7 per cent.	8 per cent.	10 per cent.
1	.971	.961	.952	.943	.935	.926	.909
2	.943	.925	.907	.890	.873	.857	.827
3	.915	.889	.864	.840	.816	.794	.751
4	.888	.855	.823	.792	.763	.735	.683
5	.863	.822	.783	.747	.713	.681	.621
6	.837	.790	.746	.705	.666	.630	.565
7	.813	.760	.711	.665	.623	.584	.513
8	.789	.731	.677	.627	.582	.540	.467
9	.766	.703	.645	.592	.544	.500	.424
10	.744	.676	.614	.558	.508	.463	.386
11	.722	.650	.585	.527	.475	.429	.351
12	.701	.625	.557	.497	.444	.397	.319
13	.681	.601	.530	.469	.415	.368	.290
14	.661	.577	.505	.442	.388	.340	.264
15	.642	.555	.481	.417	.362	.315	.240
16	.623	.534	.458	.394	.339	.292	.218
17	.605	.513	.436	.371	.317	.270	.198
18	.587	.494	.415	.350	.296	.250	.180
19	.570	.475	.396	.330	.276	.232	.164
20	.554	.456	.377	.312	.258	.215	.149
21	.537	.439	.359	.294	.241	.199	.135
22	.522	.422	.342	.277	.226	.184	.123
23	.507	.406	.326	.262	.211	.170	.112
24	.492	.390	.310	.247	.197	.158	.102
25	.478	.375	.295	.233	.184	.146	.092
26	.464	.361	.281	.220	.172	.135	.084
27	.450	.347	.268	.207	.161	.125	.076
28	.437	.333	.255	.196	.150	.116	.069
29	.424	.321	.243	.185	.141	.107	.063
30	.412	.308	.231	.174	.131	.099	.057
31	.400	.296	.220	.164	.123	.092	.052
32	.388	.285	.210	.155	.115	.085	.047
33	.377	.274	.200	.146	.107	.079	.043
34	.366	.264	.190	.138	.100	.073	.039
35	.355	.253	.181	.130	.094	.068	.036
36	.345	.244	.173	.123	.087	.063	.032
37	.335	.234	.164	.116	.082	.058	.029
38	.325	.225	.157	.109	.076	.054	.027
39	.316	.217	.149	.103	.071	.050	.024
40	.307	.208	.142	.097	.067	.046	.022
42	.289	.193	.129	.086	.058	.039	.018
44	.272	.178	.117	.077	.051	.034	.015
46	.257	.165	.106	.068	.044	.029	.013
48	.242	.152	.096	.061	.039	.025	.010
50	.228	.141	.087	.054	.034	.021	.009

TABLE III.—ANNUAL DEPOSIT IN SINKING FUND TO REDEEM $1 IN 1 TO 50 YEARS.

Rate of per cent interest at which the annuities are compounded annually.

Years to run.	2	2¼	2½	2¾	3	3¼	3½	3¾	4	4½	5	5½	6
2....	.49505	.49450	.49378	.49323	.49269	.49205	.49142	.49081	.49020	.48900	.48780	.48662	.48543
3....	.32672	.32594	.32514	.32435	.32356	.32275	.32194	.32113	.32036	.31877	.31721	.31563	.31410
4....	.24263	.24174	.24084	.23993	.23902	.23814	.23726	.23638	.23550	.23374	.23201	.23029	.22860
5....	.19216	.19118	.19024	.18930	.18835	.18742	.18649	.18556	.18463	.18279	.18098	.17918	.17739
6....	.15853	.15753	.15656	.15558	.15461	.15364	.15267	.15173	.15079	.14888	.14702	.14518	.14336
7....	.13452	.13351	.13249	.13150	.13051	.12954	.12857	.12759	.12661	.12467	.12282	.12096	.11913
8....	.11651	.11548	.11447	.11346	.11246	.11147	.11048	.10950	.10853	.10660	.10472	.10286	.10103
9....	.10252	.10148	.10046	.09945	.09844	.09744	.09644	.09546	.09449	.09257	.09069	.08883	.08702
10....	.09133	.09029	.08925	.08824	.08724	.08624	.08524	.08426	.08329	.08138	.07950	.07767	.07587
11....	.08218	.08114	.08011	.07909	.07807	.07708	.07609	.07512	.07415	.07225	.07039	.06857	.06679
12....	.07456	.07352	.07249	.07147	.07046	.06947	.06848	.06751	.06655	.06467	.06283	.06103	.05928
13....	.06812	.06708	.06605	.06504	.06403	.06305	.06206	.06110	.06014	.05827	.05645	.05468	.05296
14....	.06260	.06156	.06054	.05953	.05853	.05755	.05657	.05562	.05467	.05282	.05102	.04928	.04758
15....	.05783	.05679	.05577	.05477	.05377	.05279	.05182	.05088	.04994	.04811	.04634	.04462	.04296
16....	.05365	.05262	.05160	.05060	.04961	.04864	.04768	.04670	.04582	.04401	.04227	.04058	.03895
17....	.04997	.04894	.04793	.04694	.04595	.04499	.04404	.04312	.04220	.04042	.03870	.03704	.03544
18....	.04670	.04567	.04467	.04369	.04271	.04176	.04082	.03990	.03899	.03724	.03554	.03392	.03236
19....	.04378	.04276	.04176	.04078	.03981	.03887	.03794	.03704	.03614	.03440	.03275	.03115	.02962
20....	.04115	.04014	.03914	.03818	.03722	.03629	.03536	.03447	.03358	.03187	.03024	.02868	.02718
25....	.03122	.03024	.02927	.02835	.02743	.02655	.02567	.02484	.02401	.02244	.02095	.01955	.01823
30....	.02465	.02370	.02278	.02190	.02102	.02019	.01937	.01860	.01783	.01639	.01505	.01380	.01265
35....	.02000	.01909	.01820	.01737	.01654	.01577	.01500	.01429	.01358	.01227	.01107	.00997	.00897
40....	.01655	.01568	.01484	.01405	.01326	.01254	.01183	.01117	.01052	.00934	.00828	.00732	.00646
45....	.01391	.01307	.01227	.01152	.01078	.01012	.00945	.00885	.00826	.00720	.00626	.00543	.00470
50....	.01182	.01102	.01026	.00956	.00887	.00825	.00763	.00709	.00655	.00560	.00478	.00406	.00344

Sinking Fund Tables.—Table III is a sinking fund table, or annuity table, that gives the deposit that must be annually placed in a fund drawing compound interest to amount to $1 at the end of a given term of years.

Let

d = annuity, or sum deposited at the end of each year, which will amount to $1 in n years.

r = rate of interest, interest payments being made at the end of each year.

n = number of years.

Then

$$d = \frac{r}{(1+r)^n - 1}$$

Table III gives the values for d, for any rate of interest (r) and any term of years (n).

If it is desired to redeem an investment of, say, $1,200, at the end of 25 years, interest being 4%, Table III gives $d = 0.02401$, which would redeem $1. Hence $0.02401 \times \$1,200 = \$28.812$, which is the annual deposit in the sinking fund necessary to redeem the $1,200.

Table IV is also a sinking fund table, its values being the reciprocals of the corresponding values in Table III. Table IV gives the accumulation of annual deposits of $1 at the end of each year and the interest on the same compounded annually. The use of this table involves the operation of division, which is not ordinarily so rapid as the operation of multiplication. To illustrate, let us assume the same problem as before: It is desired to ascertain the annual deposit in a sinking fund necessary to redeem $1,200 at the end of 25 years, interest being 4%. Table IV gives the accumulation of $1 in 25 years at 4% as being $41.66. Hence $\$1,200 \div 41.66 = \$28.805$. This is not quite the same as the result secured with Table III, due to the fact that Table IV is not carried out to as many decimal places.

Present Worth of Annuity.—Table V is useful in determining the justifiable present expenditure to save $1 per year for various terms of years. In other words, Table V gives the capital sum that will return $1 per year in interest during the term of years and will also return an additional sum in interest each year sufficient to extinguish the principal at the end of a term of years if placed at compound interest.

The present worth, W, of an annuity is given by the formula

$$W = \frac{(1+r)^n - 1}{(1+r)^n \, r}$$

Table V was calculated by this formula.

References and Cross-References.—At the end of the Waterworks Section of this book will be found an abstract of an excellent article by Mr. Leonard Metcalf on the appraisal of waterworks, wherein are given various sinking fund formulas and curves.

For the deduction of the formulas given in the preceding pages, consult any higher algebra, or Frye's "Civil Engineer's Pocketbook."

TABLE IV.—SINKING FUND.

(The amount (or accumulation) when $1 is deposited annually in a fund whose interest is compounded.)

At End of Year.	2	3	4	5	6	7	8
	—Rate of Interest, Per Cent.—						
1	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2	2.02	2.03	2.04	2.05	2.06	2.07	2.08
3	3.06	3.09	3.12	3.15	3.18	3.21	3.25
4	4.12	4.18	4.25	4.31	4.37	4.44	4.51
5	5.20	5.31	5.42	5.52	5.64	5.75	5.87
6	6.31	6.47	6.63	6.80	6.98	7.15	7.34
7	7.43	7.66	7.90	8.14	8.39	8.65	8.92
8	8.58	8.89	9.21	9.55	9.90	10.26	10.64
9	9.75	10.16	10.58	11.03	11.49	[illegible]	12.49
10	10.95	11.46	12.01	12.57	13.18	13.82	14.49
11	12.17	12.81	13.49	14.21	14.97	15.78	16.65
12	13.41	14.19	15.03	15.91	16.87	17.89	18.98
13	14.68	15.62	16.63	17.71	18.88	20.14	21.50
14	15.97	17.09	18.29	19.60	21.01	22.55	24.22
15	17.29	18.60	20.02	21.58	23.27	25.13	27.15
16	18.64	20.16	21.82	23.65	25.67	27.89	30.33
17	20.01	21.76	23.70	25.84	28.21	30.84	33.75
18	21.41	23.42	25.66	28.13	30.90	34.00	37.45
19	22.84	25.12	27.68	30.54	33.76	37.38	41.45
20	24.30	26.87	29.79	33.06	36.78	41.00	45.76
21	25.78	28.68	31.98	35.72	39.99	44.86	50.43
22	27.30	30.54	34.26	38.50	43.39	49.01	55.46
23	28.84	32.46	36.63	41.43	46.99	53.44	60.90
24	30.42	34.43	39.10	44.50	50.81	58.18	66.77
25	32.03	36.46	41.66	47.72	54.86	63.25	73.11
26	33.67	38.56	44.33	51.11	59.15	68.68	79.96
27	35.34	40.71	47.10	54.66	63.70	74.48	87.35
28	37.05	42.93	49.98	58.39	68.52	80.70	95.34
29	38.79	45.22	52.98	62.31	73.64	87.35	103.97
30	40.57	47.58	56.10	66.43	79.05	94.46	113.29
31	42.38	50.01	59.34	70.75	84.80	102.07	123.35
32	44.23	52.51	62.72	75.29	90.88	110.22	134.22
33	46.11	55.08	66.23	80.05	97.34	118.93	145.96
34	48.03	57.73	69.88	85.05	104.18	128.26	158.63
35	50.00	60.46	73.67	90.31	111.43	138.24	172.32
36	51.99	63.28	77.62	95.82	119.11	148.91	187.11
37	54.03	66.18	81.72	101.61	127.26	160.34	203.08
38	56.11	69.16	85.99	107.69	135.90	172.56	220.33
39	58.24	72.24	90.43	114.08	145.06	185.64	238.95
40	60.40	75.40	95.05	120.78	154.75	199.63	259.07
41	62.61	78.67	99.85	127.82	165.04	214.61	280.79
42	64.86	82.03	104.84	135.21	175.94	230.63	304.26
43	67.16	85.49	110.04	142.97	187.50	247.78	329.60
44	69.50	89.05	115.44	151.12	199.75	266.12	356.97
45	71.89	92.72	121.06	159.68	212.73	285.75	386.52
46	74.33	96.51	126.90	168.66	226.50	306.75	418.44
47	76.82	100.40	132.98	178.10	241.09	329.22	452.92
48	79.35	104.41	139.30	188.00	256.55	353.27	490.15
49	81.94	108.55	145.87	198.40	272.94	379.00	530.37
50	84.58	112.80	152.70	209.32	290.32	406.54	573.80

TABLE V.—PRESENT WORTH OF ANNUITY.

Showing Justifiable Present Expenditure to Save $1 Per Year for Various Terms of Years.

Term of Years.	Justifiable Present Expenditure with Interest at— 3 per cent.	4 per cent.	5 per cent.	6 per cent.	7 per cent.	8 per cent.	9 per cent.	10 per cent.
1..........	$0.97	$0.96	$0.95	$0.94	$0.93	$0.93	$0.92	$0.91
2..........	1.91	1.89	1.86	1.83	1.81	1.78	1.76	1.74
3..........	2.83	2.78	2.72	2.67	2.62	2.58	2.53	2.49
4..........	3.72	3.63	3.55	3.47	3.39	3.31	3.24	3.17
5..........	4.58	4.45	4.33	4.21	4.10	3.99	3.89	3.79
6..........	5.42	5.24	5.08	4.92	4.77	4.62	4.49	4.36
7..........	6.23	6.00	5.79	5.58	5.39	5.21	5.03	4.87
8..........	7.02	6.73	6.46	6.21	5.97	5.75	5.53	5.34
9..........	7.79	7.44	7.11	6.80	6.52	6.25	6.00	5.76
10..........	8.53	8.11	7.72	7.36	7.02	6.71	6.42	6.14
11..........	9.25	8.76	8.31	7.89	7.50	7.14	6.81	6.50
12..........	9.95	9.39	8.86	8.38	7.94	7.54	7.16	6.81
13..........	10.64	9.99	9.39	8.85	8.36	7.90	7.49	7.10
14..........	11.30	10.56	9.90	9.30	8.75	8.24	7.79	7.37
15..........	11.94	11.12	10.38	9.71	9.11	8.56	8.06	7.61
16..........	12.56	11.65	10.84	10.11	9.45	8.85	8.31	7.82
17..........	13.17	12.17	11.27	10.48	9.76	9.12	8.54	8.02
18..........	13.75	12.66	11.69	10.83	10.06	9.37	8.76	8.20
19..........	14.32	13.13	12.09	11.16	10.34	9.60	8.95	8.37
20..........	14.88	13.59	12.46	11.47	10.59	9.82	9.13	8.51
21..........	15.42	14.03	12.82	11.76	10.84	10.02	9.29	8.65
22..........	15.94	14.45	13.16	12.04	11.06	10.20	9.44	8.77
23..........	16.44	14.86	13.49	12.30	11.27	10.37	9.58	8.88
24..........	16.94	15.25	13.80	12.55	11.47	10.53	9.71	8.99
25..........	17.41	15.62	14.09	12.78	11.65	10.67	9.82	9.08
26..........	17.88	15.98	14.38	13.00	11.83	10.81	9.93	9.16
27..........	18.33	16.33	14.64	13.21	11.99	10.94	10.03	9.24
28..........	17.76	16 66	14.90	13.41	12.14	11.05	10.12	9.31
29..........	19.19	16.98	15.14	13.59	12.28	11.16	10.20	9.37
20..........	14.88	13.59	12.46	11.47	10.59	9.82	9.13	8.51
31..........	20.00	17.59	15.59	13.93	12.53	11.35	10.34	9.48
32..........	20.39	17.87	15.80	14.08	12.65	11.43	10.41	9.53
33..........	20.77	18.15	16.00	14.23	12.75	11.51	10.46	9.57
34..........	21.13	18.41	16.19	14.37	12.85	11.59	10.52	9.61
35..........	21.49	18.67	16.37	14.50	12.95	11.65	10.57	9.64
36..........	21.83	18.91	16.55	14.62	13.04	11.72	10.61	9.68
37..........	22.17	19.14	16.71	14.74	13.12	11.78	10.65	9.71
38..........	22.49	19.37	16.87	14.85	13.19	11.83	10.69	9.73
39..........	22.98	19.58	17.02	14.95	13.26	11.88	10.73	9.76
40..........	23.12	19.79	17.16	15.05	13.33	11.93	10.76	9.78
41..........	23.41	19.99	17.29	15.14	13.39	11.97	10.79	9.80
42..........	23.70	20.19	17.42	15.23	13.45	12.01	10.81	9.82
43..........	23.98	20.37	17.55	15.31	13.51	12.04	10.84	9.83
44..........	24.25	20.55	17.66	15.38	13.56	12.08	10.86	9.85
45..........	24.52	20.72	17.77	15.46	13.61	12.11	10.88	9.86
46..........	24.78	20.89	17.88	15.52	13.65	12.14	10.90	9.88
47..........	25.03	21.04	17.98	15.59	13.69	12.16	10.92	9.89
48..........	25.27	21.20	18.08	15.65	13.73	12.19	10.93	9.90
49..........	25.50	21.34	18.17	15.71	13.77	12.21	10.95	9.91
50..........	25.73	21.48	18.26	15.76	13.80	12.23	10.96	9.92

Identity of Machine and Engineering Structure.—An engineering structure that performs a useful service is, in essence, a machine. A railway is a machine for manufacturing transportation. A street or road is part of a similar machine, the vehicles being the other part. Buildings are part of a manufacturing plant. Even when built merely to rent, they are machines for producing rentable floor area.

In solving problems in engineering economics, the young engineer will be greatly aided by keeping in mind this identity of what is commonly called a "machine" and what is commonly called a "structure."

Problem 1. Which of Two New Machines (or Structures) to Select.—This problem consists in determining which machine yields the desired number of units of product at the lowest cost.

Let

N = number of units produced annually by the 1st machine.
n = number of units produced annually by the 2d machine.
C = first cost of the 1st machine.
c = first cost of the 2d machine.
D = per cent of annual renewals, or annuity in sinking fund for 1st machine.
d = per cent of annual renewals, or annuity in sinking fund, for 2d machine.
R = per cent of annual repairs for 1st machine.
r = per cent of annual repairs for 2d machine.
I = per cent of annual interest on capital.
O = annual operating expense of 1st machine.
o = annual operating expense of 2d machine.
U = unit cost of production with 1st machine.
u = unit cost of production with 2d machine.

Then

$$(1)\quad U = \frac{O + RC + DC + IC}{N}$$

$$(2)\quad u = \frac{o + rc + dc + Io}{n}$$

Since U must be less than u, to warrant the selection of the 1st machine in preference to the second, we have

$$(3)\quad \frac{O + RC + DC + IC}{N} < \frac{o + rc + dc + Ic}{n}$$

Ordinarily, the number of units to be produced by each of the two machines is equal, or $N = n$. Then we have:

$$(4)\quad O + RC + DC + IC < o + rc + dc + Ic$$

Expressed in words we have this criterion:

Select the machine that shows the least sum of these four items of cost: (1) annual operating expense, (2) average annual repairs, (3) average annual renewals, and (4) annual interest on the investment.

Note carefully that there are two different methods of determining D, the percentage of first cost allowed for annual renewals. By the

method in vogue on railways, D is the reciprocal of the life of a machine, hence for a locomotive having a life of 25 years, D is 4%. By the method often used for smaller plants, D is the annuity placed in a sinking fund to redeem to the investment in a machine at the end of its life. In the first case, renewals are treated like current expenses for repairs, and this is justified where a large number of plant units of different ages are in operation.

Formula (4) can be put in another form, thus:

$$(5)\quad I(C-c) < (o+rc+dc)-(O+RC+DC)$$

A still more common form is this:

$$(6)\quad C-c < \frac{(o+rc+dc)-(O+RC+DC)}{I}$$

Between two new machines of equal capacity, the higher first cost of one is economically justified when its excess cost is less than the capitalized saving in annual operating and maintenance expenses due to its use.

For the benefit of young engineers the meaning of the word "capitalize" should be explained.

To capitalize an annual expense consists in dividing it by the rate of interest at which money can be borrowed.

Thus, if a man is required to perform a certain class of work at an annual expense of $600, and if the rate of interest is 6%, the capitalized cost of this annual expense is $600 ÷ 6% = $10,000.

Reverting to the rule following formula (6) we see that it is the one which Wellington has applied to the various problems of railway location in his "Economic Theory of Railway Location." I prefer, however, to use the criterion as given in formula (6), because sight is not then lost of the fact that maintenance expenses are a function of the first cost of the machine under consideration. That this is an important improvement over Wellington's criterion will be seen when one examines Wellington's data on the maintenance of locomotives, as well as other maintenance data in his book. There the maintenance is recorded not as a percentage of the first cost of the locomotive but in the train-mile as the unit. Yet Wellington knew that the first cost was a factor in maintenance cost, for he says (p. 144 of his book): "Half the total cost of engine repairs varies as the weight, and half is independent thereof." Incidentally, I may say that he was entirely wrong in this conclusion, for the cost of annual repairs varies almost directly as the weight of a locomotive. Again he speaks (p. 148) of the fact that passenger engines cost about 20% less for repairs than freight engines, without recognizing that the difference in weight and first cost was what accounted for this difference in repairs.

Formula (3) or (6) should be invariably used not only by engineers who are selecting or designing machines for a given purpose, but by engineers who are designing structures of all kinds. I have already stated that engineering structures should be regarded either as machines or as parts of machines. At first sight it may appear that some structures are not at all like machines in that they seemingly have no operating expense (O).

In the case of a country road, for example, the item of operating expense (O) may appear to be non-existent; although, in fact, a little thought makes it clear that the owners of the horses and wagons, motor cars, etc., pay this operating expense, which should be as certainly considered by the engineer who is locating and designing a road or street as it would be considered if he were locating and designing a railway.

In certain classes of work, serious error will occur if there is failure to give proper consideration to N and n in formula (1). This is strikingly seen in the ordinary designs of country highways, where failure to determine the number of ton-miles ($=N$) to be hauled annually leads to the most glaring blunders in designing the road.

In selecting an engine for a given purpose, the same error is frequent. The engineer whose mind is fixed upon economy of fuel, for example, is very apt to choose a type of engine so expensive in first cost that the unit interest $\frac{I}{N}$ is so greatly increased as to exceed greatly the unit fuel saving.

A blunder often made by contractors is the selection of a machine that is too large for the work in hand. Not only does too large a machine increase the unit interest and unit maintenance, but it often increases the unit operating expense $\frac{O}{N}$, due to the fact that its size makes it expensive to move or shift from place to place. This is particularly true of large steam shovels used on small excavations.

The item of operating expense (O), as the term is here used, includes supervision, taxes, labor (except for maintenance), fuel and other supplies, materials, etc.

Some statisticians insist that taxes should not be regarded as an operating expense, because unit taxes tend to increase while other unit operating items tend to decrease as the plant grows in size. Even if this were true, I fail to see sufficient reason for segregating taxes with fixed charges. But I deny the truth of the statement that unit taxes must necessarily increase. If corporations have lied to tax assessors, then unit taxes do eventually increase when the lies are found out, and that is precisely what has caused most of the increase in unit taxes in recent years. The subject, however, is not one of sufficient importance in this connection to merit more than passing notice.

The item of annual repairs (RC) is commonly underestimated, and is grossly underestimated in the majority of instances that I have seen in print.

The cost of annual repairs is not a constant for each year, but increases, at least for a time, as the plant grows older. Hence, if estimates of maintenance are based upon the maintenance costs during the earlier part of the life of a machine (or structure), serious errors result. This subject will receive consideration at greater length in subsequent pages.

The item of renewals (DC) relates to entire renewals of plant

units, such as the entire renewal of a locomotive. The rate, D, may be the reciprocal of the life of the plant unit. Thus if the life is 20 years, the annual rate of renewal (D) is 5%. Many engineers prefer to use the annuity deposited in a sinking fund, instead of this rate of renewal, D. In such a case, use Table III. For example, a life of 20 years, with interest at 5%, would require an annual deposit of $0.0372 to redeem $1, which is equivalent to 3.72% rate to be used instead of the 5% obtained by the straight line formula.

I prefer, however, not to use the sinking fund method in cases where a large number of similar plant units are under consideration, as in the case of a railway. The reasons for this preference will be given subsequently.

Problem II. When to Retire An Old Machine in Favor of An Improved or Larger One.—Like Problem I, this problem involves the determination of unit costs of production. We shall, therefore, use the same symbols as on page 17, with the addition of

c_1 = salvage value of the old machine.

Then the unit cost of production with the new machine will be

$$(7) \quad U = \frac{O + RC + DC + I(C - c_1)}{N}$$

and

$$(8) \quad u = \frac{o + rc + dc + Ic}{u}$$

Since U must be less than u to warrant the purchase of the new machine, we have

$$(9) \quad \frac{O + RC + DC + I(C - c_1)}{N} < \frac{o + rc + dc + Ic}{n}$$

Ordinarily the new machine is expected merely to turn out as many units of product as the old machine is already delivering, in which case $N = n$, and we have

$$(10) \quad O + RC + DC + I(C - c_1) < o + rc + dc + Ic$$

Whence

$$(11) \quad C - (c + c_1) < \frac{(O + RC + DC) - (o + rc + dc)}{I}$$

In words this means: *The purchase of an improved machine of the same capacity as the old is economically justified when its excess first cost over the sum of the first cost and salvage value of the old machine is less than the capitalized saving in annual operating expense and maintenance effected by the new machine.*

If $c_1 = o$, formula (11) becomes identical with formula (6), because the old machine has then perished, and we are comparing two entirely new machines. If the old machine can be disposed of for its full first cost, then $c_1 = c$, and formula (11) becomes:

$$(12) \quad C - 2c < \frac{(O + RC + DC) - (o + rc + dc)}{I}$$

Expressed in words this is: *If an old machine has a salvage value equal to its full first cost, the purchase of an improved machine is justified if the excess cost of the new machine over double the first*

cost of the old machine is greater than the capitalized saving in annual operating expense and maintenance effected by the new machine. This is a condition rarely existing, but it is well worth remembering as indicating an extreme case which may be approached more or less closely at times.

The Life of a Machine or Structure and the Growth of Annual Repairs.—Probably no subject in engineering economics has been enveloped in a greater haze of contradictory opinions than this. Many eminent engineers maintain the doctrine that the curve of annual maintenance resembles some sinking fund accumulation curve—a doctrine that rests wholly on speculation and has never had a single curve of actual maintenance cost adduced in its support, so far as I have been able to discover. Actual curves of machine repairs of individual machines are ordinarily not regular curves at all, but are saw-toothed lines, usually of great irregularity.

As fairly typical of a large class of machines, I will take a railway freight car, whose wheels, axles, brasses, brakes, draw-bars, trusses, paint, etc., constitute the separate parts subject to the wear and tear due to use and exposure to the elements. The life of each of these parts is the average life, and the cost of renewal of the part is the cost ascertained by deducting the scrap value from the original value of the part in place. This is not strictly correct, for the labor of renewing a part is usually greater than the labor originally involved in assembling the parts. For our present purpose, however, this difference is not material.

Table VI gives the data for a small box car of about 30,000 lbs. capacity, and will serve our purpose if we bear in mind that it slightly underestimates the actual cost of renewals of parts, for the reason above given.

TABLE VI.—BOX CAR REPAIRS.

Truck: Item.		First cost.	Scrap value.	Net cost repairs.	Life, years.	Average annual repairs.
(1)	Wheels	$ 90	$ 35	$ 55	4	$13.75
(2)	Axles	45	15	30	8	3.75
(3)	Brasses	10	4	6	3	2.00
(4)	Frame	95	25	70	35	2.00
	Total truck	$240	$ 79	$161	..	$21.50
	Box:					
(5)	Brakes	$ 10	$ 2	$ 8	6	$ 1.33
(6)	Draw-bars	29	6	23	6	3.83
(7)	Frame	60	10	50	15	3.33
(8)	Roof	29	4	25	8	3.12
(9)	Floor	12	1	11	10	1.10
(10)	Sides	44	2	42	20	2.10
(11)	Painting	8	0	8	7	1.14
(12)	Trimmings	20	3	17	20	0.85
(13)	Trusses	6	3	3	20	0.15
	Total box	$218	$ 31	$187	..	$16.95
	Grand total	$458	$110	$348	..	$38.45

There are 13 parts given in Table VI. If we add their lives, as given in the last column, and divide by 13, we get 12.2 years, which might be called the "unweighted" average life. It is obviously not the true average.

If we divide the total average annual repairs, $38.45, into the total net cost of repairs, $348, we get 9.1, which has been called the "average life of the car," but this, too, is deceptive. Nor would it be more correct to divide the total first cost, $458, by $38.45, for the quotient, 11.9, is not the average life. The fact is, that the average life of a car, taken as a whole, bears no necessary relation to the average life of any or all its parts, as will be explained more fully later on. Average annual repairs, such as the $38.45 given in Table VI, is an item involving credits for scrap value, thus making it impossible to derive the average life of the parts, using life in any true sense of the word. The average life of a machine is not deducible from its average annual repairs.

Referring to Table VI, we see that the life of the frame of the truck is 35 years. Therefore, before the frame requires renewal, nearly all the other parts will have been renewed several times. If the frame were assigned a life of 40 years, there would not be a single part that had not required at least two lives to equal the life of the frame. But the life of the longest lived part does not itself determine the life of the machine, for, as in this case of the car, a new truck frame might be provided at the end of 35 years. Then the car would be prepared to go on living another 35 years.

We see, then, that the average life of a machine taken as a whole may bear no necessary relation to the average life of any of its parts, even of its longest lived part. The fact is that the actual life of most machines is determined by no self-contained elements of destruction, but by "improvements in the art" or by increase in the service required of the machine, necessitating, in the first case, an improved machine, and, in the second case, a larger machine. The death of most machines is, therefore, caused by *obsolescence*—the machine having outlived its economic usefulness, though still capable of rendering service. In America, the actual average life of railway cars and locomotives has not much exceeded 20 to 25 years. In Europe and England, cars and locomotives more than half a century old are in common use yet. On the whole Northern Pacific Railway (U. S.) the oldest locomotive is only 33 years old. Such is the difference in obsolescence in America and Europe. In a growing community it is obvious that obsolescence of certain classes of machines will be much more rapid than in a community whose growth is slow. Thus, a pump may economically serve a waterworks in a growing community not longer than ten years, while the same pump might economically serve a non-growing community for thirty years, or more, provided no radical improvement in pump design were effected.

In America we have had not only rapidly growing communities, but ingenious men and aggressive business managers who have been little hampered by labor union resistance to improved machinery. Hence obsolescence of machinery due to "improvements in the art" has played a very important part. I think I am safe in saying that the vast majority of machines in America have had a life averaging not to exceed about 20 years. Often the life of certain classes has

not been five years. Witness the short life of cable railways in our large cities, due to the rapid improvement in electric car transportation. Cableway systems had been hardly installed in New York and Philadelphia before they were torn out to make way for electric traction.

While the total actual life of a machine is usually independent of the amount of service it renders, but is usually determined by obsolescence, the life of the parts of the machine is determined by three factors: (1) The activity of use; (2) the care in lubrication, etc., to reduce wear; and (3) the amount and character of exposure to the elements.

Activity of use is an exceedingly important factor in the wear of most machine parts. Hence records of repair costs should give some statement of work done that will indicate the activity of the machine. Thus, the car-miles per year will show the activity of a car. The number of hours of actual work per year is often a sufficient index as to work done. A steam road roller usually works about 100 days of 10 hours, or 1,000 hours per year. A locomotive usually works nearly three times that number of hours, and its annual repairs form about three times as great a percentage of the first cost as the percentage of repair cost of a steam roller.

A rock drill working two shifts of 8 hours daily will show almost twice the annual repairs incurred when only one daily shift is worked. Incidentally, I may add that under severe and constant service, the annual cost of repairs of a rock drill may exceed the first cost of the machine.

Fortunately there are many classes of service that differ so little that annual repair costs or life of parts can be correctly judged without having at hand a statement as to the precise activity of the machine.

Let us now plot the costs of car repairs given in Table VI, so as to secure a curve of actual annual repairs. To do so we must first tabulate the recurring costs of renewals of parts given in Table VI as follows:

End of year.	Items repaired.	Total Repairs.
1	None	None
2	None	None
3	(3) Brasses	$ 6
4	(1) Wheels	$ 55
5	None	None
6	(3), (5) and (6)	$ 36
7	(11)	$ 8
8	(1), (2) and (8)	$ 110
9	(3)	$ 6
10	(9)	$ 11
11	None	None
12	(1), (3), (5) and (6)	$ 92
13	None	None
14	(11)	$ 8
15	(3) and (7)	$ 56
16	(1), (2) and (8)	$ 110
17	None	None
18	(3), (5) and (6)	$ 36
19	None	None
20	(1), (9), (10), (12) and (13)	$ 86

Plotting the total annual repairs, for this 20 year period, we have the "curve" shown in Fig. 1, which bears no resemblance whatever to the "sinking fund curve of depreciation."

I have not carried the "curve" out to the 35 year period (the life of the truck frame), since our present purpose is fully served by considering the 20 year period.

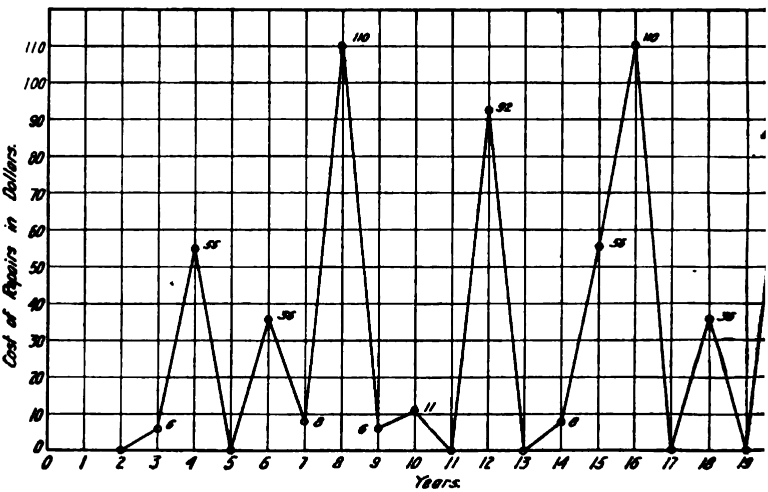


Fig. 1. Repairs of Freight Car.

This saw-toothed "curve" of annual repairs of individual cars obviously will resolve itself into a straight line if the total annual repairs to a large number of different cars of slightly different ages is taken. During the first eight years of life of a group of wooden box cars, the total annual repairs will increase rapidly, but after that there will be comparatively little increase in the totals for each year.

The same general law holds of all machines in active and regular service. For a period there will be a rising cost of repairs, determined, as to rapidity of rise, by the life and cost of the various parts. Eventually the curve of repairs will become a saw-tooth line, whose general direction is either horizontal or slightly ascending. In no class of machine of which at present I have knowledge is there a repair curve bearing the remotest resemblance to a curve derived by plotting any function of any "sinking fund formula."

I should leave the discussion of this subject in somewhat incomplete form were I not to touch upon such structures (or parts of machines) whose life is terminated by the various forms of chemical change. The rusting of iron, the rotting of wood (due to fungi), the decay of asphalt (due to little understood chemical action), and various other forms of plant deterioration fall into one general class for which it may be possibly claimed that annual repairs of individual units follow some sort of regular curve, ascending rapidly toward the close of life. I think that the reasoning that has led to such a belief can readily be seen to be fallacious, if we start out by drawing a sharp distinction between the annual repairs required by a single unit and the annual repairs of a group of similar units.

Let us take a railway cross-tie of untreated yellow pine, for example. If we confine our attention to one tie, we shall find that for, say, 7 years it gives perfectly uniform service without requiring any particular attention. Then, perhaps, the qualities by virtue of which it has resisted decay, begin to depart, and rot fungus gains a hold here and there. The growth of this fungus under the rail may result in the decay of the wood fibres to such an extent that a spike works loose and the track foreman finds it necessary to pull the spike and drive it in another place. Some time later he may shift the tie slightly and redrive all the spikes. Finally he decides that the tie is so weakened by decay as to be unsafe, and removes it. The current repairs (the spike pulling, shifting, etc.) have been so slight in cost as to be entirely negligible when compared with the one great repair of entire renewal of the tie. Hence there exists no curve of repairs for this single tie at all, other than the one final upleap in the "curve," due to its renewal.

Let us see now what happens to a group of the same ties. Each tie differs slightly from the others, both in its physical and chemical make up. The character of the service differs also. One tie is near a rail joint, another is not. Some ties are on curves, some on tangents. Some are near soil where the spores of rot fungus are numerous, others are not. Hence at the end of, say, 5 years, some ties are so badly rotted that they must come out of the track; at the end of 10 years many ties are still in service, although the great majority may have been removed at the end of 8 or 9 years. Now if we plot the curve of annual tie renewals of this group of ties, we shall find it following the zero line for 5 years, then slightly ascending until about 8 years when it takes a sudden leap upward for a year or two—and all is over. This final action and sudden rise in the renewal curve indicates the somewhat varying life of the different ties, and nothing more.

The repairs of an asphalt pavement show a similar sudden rise toward the end of the life of the asphalt, and for similar reasons. Each square yard of the asphalt may be regarded as a unit similar to a railway tie. Slight original differences in chemical and physical constitution exist in the different square yards. Differences in severity of traffic exist in different places. Hence, as in the case of a group of railway ties of the same age, there will be differences in the life of different square yards of asphalt. This will show in the sudden rise of annual repairs of asphalt pavement after 15 to 20 years of life.

In general, any machine or structure consisting of a number of parts of equal age and subject to about the same exposure to the elements, or to wear, will have a curve of repairs that will eventually take a sudden rise. *This rise in repairs is simply the evidence of the termination of the life of the group of units composing the machine or structure.* If the machine or structure is of a kind that permits the economic renewal of each of those units by itself, as in the case of railway ties or rails, no problem in economics presents itself.

There is obviously nothing to do but to renew each unit as rapidly as it reaches the limit of its endurance.

If, on the other hand, the units are so interrelated that the renewal of single units is more expensive than the renewal of the entire group of units at one time, then a problem in economics does present itself, the question being this: When does the rising curve of cost of repairs to the expiring units reach a point where it becomes economic to abandon the entire group of units and procure a new group of units?

This problem is not one that comes before many classes of engineers, but it does present itself to highway engineers, particularly in connection with repairs to asphalt pavements. In view of this fact, and because several entirely erroneous solutions of the problem have been published by engineers eminent in the field of highway engineering, I have prepared a correct solution of the problem. (See page 27.)

While on the subject of repairs, it may be well to discuss briefly the identity of repairs and renewals in cases where a plant is being operated with a large number of plant units of different ages.

A railway is a plant for manufacturing transportation, as Wellington has well put it. The principal plant elements are:

1. Roadbed.
2. Ballast.
3. Ties.
4. Rails.
5. Buildings.
6. Rolling stock, or equipment.
7. Repair shops and tools.

Minor repairs of roadbed and track are being constantly made.

A bolt is renewed here, a spike there, a bit of ballast in another place—all renewals of plant on a minor scale. About 10% of the wooden ties are replaced annually—renewals again, though on a larger scale. About 5% of the rails are replaced annually—still more renewals. About 4% of the cars and locomotives are entirely renewed annually—renewals on a still larger scale. But from the worn-out track bolt to the worn-out locomotive, we have renewals of plant elements, varying in size and cost, it is true, but differing not one whit in the real character of the process.

Evidently, then, after any large plant has been in use for a considerable period of years, there is no logical reason for distinguishing between minor renewals (called repairs) and major renewals (called renewals, or "entire renewals"). They are all one and the same thing in fact, differing only in degree. Accountants have preached for a century or more about the dire consequences of failure to provide sinking funds for the redemption of large plant elements at the expiration of their life. But the great majority of managers of railways, lighting companies, mills, factories and mines, have ignored the arguments of the accountants, and have gone right on without providing a fund for renewals, but regarding renewals as identically the same in nature as repairs. In this I conceive that they have been right.

The managers and owners of plants have known, what accountants have ignored, that money is worth more to a company for use in extensions and betterments of plant than it could possibly bring by placing it in a sinking fund, since all sinking funds draw comparatively small interest. This has undoubtedly been a strong actuating motive—and a sound one—with plant managers, but I am satisfied that the inherent reasonableness of regarding even large renewals as repairs must have appealed quite as strongly to the managers of large plants.

Problem III. To Determine When Repairs Have Grown so Great as to Justify Renewal.—The following discussion can be understood only after a study of the preceding paragraphs.

This problem is one that seldom arises except in considering the repairs to such a structure as an asphalt pavement, for reasons previously given. If the rising "curve of annual repairs" is either a straight line or any curve which can be expressed as an equation, an accurate solution of the problem is possible by the use of the method about to be explained, aided by the application of differential calculus.

An approximate solution is possible even without resort to the higher mathematics, as will be now shown.

For simplicity of illustration, and not because it represents actual conditions, let us first assume that repairs increase at a uniform rate. It should be clear that the problem consists in finding the minimum quotient obtained by dividing the sum of the cost of the structure and the total repairs by the number of years during which the repair curve has been steadily rising.

Let

C = first cost of structure.

R = total repairs during y years of steadily increasing repairs.

Then when

$\frac{C+R}{y}$ is a minimum we have the period beyond which it is uneconomic to continue repairs.

In other words:

The average annual first cost plus the average annual repair cost must be a minimum.

We need not consider the item of interest in first cost, for that is a constant that goes on forever, unaffected by the period of renewal of the structure. To those acquainted with calculus this statement should be self-evidently true, and to those who are not familiar with the higher mathematics it should become self-evident if they will consider the item of annual interest as being entirely analogous

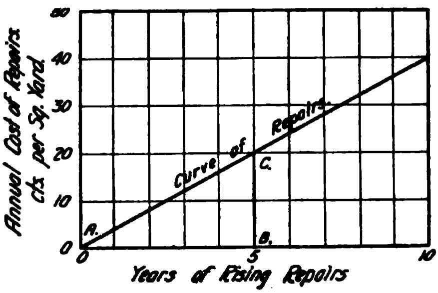


Fig. 2.

to an expense for sweeping a street, a cost that depends, it is true, upon the character and therefore the first cost of the pavement, but one having no bearing upon the question of *when* an old pavement shall be replaced by a new one of the same sort.

Let us assume that the annual repairs rise steadily, at the rate of 4 cts. increase per year. Let us assume that the first cost of this asphalt is $1 per sq. yd., not including the concrete base which is permanent, and therefore should not enter the problem any more than should the cost of sweeping, or the annual interest on the investment. Then we can show the "curve of repairs" as in Fig. 2.

By a series of approximations, we can now determine when the value of $\frac{C+R}{y}$ is a minimum. Let us first assume 5 years. Then $y = 5$. The total repairs during this five-year period can be readily

calculated by determining the area of the triangle ABC, in Fig. 2, which is $\frac{20 \times 5}{2} = \$0.50$.

Hence we have

$$\frac{C+R}{y} = \frac{\$1.00 + \$0.50}{5} = \$0.30,$$

which is the average annual first cost of the pavement and its repairs for the 5-year period. If this seems high, let us try a 4-year period. Then we have $R = \$0.32$.,

$$\frac{C+R}{y} = \frac{\$1.00 + \$0.32}{4} = \$0.33.$$

Evidently, then, the economic period is not less than 5 years, and may be greater. Let us try 10 years. Then $R = \$2.00$,

$$\frac{C+R}{y} = \frac{\$1.00 + \$2.00}{10} = \$0.75.$$

This is much higher than for the 5-year period. Let us try 7 years. Then $R = \$0.98$.

$$\frac{C+R}{y} = \frac{\$1.00 + \$0.98}{7} = \$0.27.$$

Further tests will show that this is practically the minimum. It should be noted that the minimum is attained, in this case, when the total repairs for the period of rising repairs equals the first cost of the asphalt wearing coat. As a matter of fact, this is a law of general application wherever the curve of rising annual repairs is a straight line, that is wherever repairs increase annually by any constant percentage. I will prove this generalization by the aid of calculus, but it can be demonstrated in the more roundabout and primitive way above used.

In all cases, no matter what the curve of increasing repairs may be, the method of plotting the annual repairs and determining the area, to ascertain total repairs (R) will enable anyone to find when $\frac{C+R}{y}$ is a minimum, by a series of approximations.

For the engineer who is familiar with calculus the following method will afford a more direct solution of the problem. The problem is to determine when $IC + \frac{C+R}{y} = u$ is a minimum, u being the unit annual pavement cost.

When repairs increase regularly each year, by a rate a, then the equation of a straight line $x = ay$ gives us the "curve of annual repairs." Since R is the area of a triangle whose base is y (see Fig. 2),

$$R = \frac{xy}{2},$$

But $x = ay$,

Hence $R = \frac{ay^2}{2}$.

Substituting this value of R in the equation

$$IC + \frac{C + R}{y} = u, \text{ we have}$$

$$IC + \frac{C}{y} + \frac{ay}{2} = u.$$

Differentiating, we see that IC (the annual interest) disappears, as it is a constant, and we have

$$\frac{-Cdy}{y^2} + \frac{ady}{2} = du.$$

Solving for a minimum by placing

$$\frac{du}{dy} = o, \text{ we have}$$

$$\frac{-C}{y^2} + \frac{a}{2} = o,$$

$$y^2 = \frac{2C}{a},$$

$$y = \sqrt{\frac{2C}{a}}.$$

This gives us the desired formula for determining the time (y)

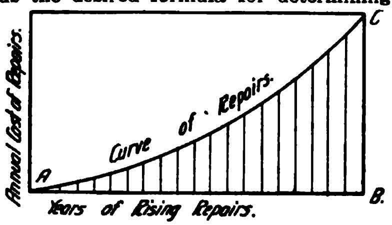


Fig. 3.

when it becomes economic to renew the entire pavement. If, as in the example above given, $a = 4\%$ of C, we have

$$y = \sqrt{\frac{200}{4}} = 7.07 \text{ years.}$$

Since the minimum average annual plant expense is attained when $y = \sqrt{\frac{2C}{a}}$, and since $R = \frac{ay^2}{2}$, we have

$$R = \frac{a}{2} \times \frac{2C}{a} = C.$$

Hence:

When annual repairs increase steadily by a constant ratio it ceases to be economic to retain a structure or machine in service after the aggregate repairs exceed the first cost of the structure or machine.

Should the structure or machine have any salvage value, substitute the expression "first cost minus salvage value" in the foregoing criterion in place of the expression "first cost."

As a further example, let us assume that the curve of annual

repairs is a parabola instead of a straight line, as indicated in Fig. 3.

The area ABC gives us the total repairs, or R; and for a parabola this external area is

$$R = \frac{xy}{3}.$$

Since the curve of the parabola is

$$y^2 = 2px, \quad x = \frac{y^2}{2p}.$$

Hence

$$R = \frac{y^3}{6p}.$$

Our equation of condition is, as before,

$$\frac{C+R}{y} = u.$$

Hence

$$\frac{C}{y} + \frac{y^2}{6p} = u.$$

Differentiating and placing

$$\frac{du}{dy} = o, \text{ we have}$$

$$\frac{-C}{y^2} + \frac{ydy}{3p} = o,$$

$$y^2 = \frac{3pC}{y},$$

$$y^3 = 3pC,$$

$$y = \sqrt[3]{3pC}.$$

Substituting the values of p and C in this equation will give us the period of years during which it continues to be economic to pay the increasing cost of repairs.

Since $R = \frac{y^3}{6p}$, and since $y = \sqrt[3]{3pC}$, combining we have

$$R = \frac{C}{2}.$$

Hence:

When annual repairs increase steadily according to the curve of a parabola, it ceases to be economic to retain a structure or machine in service after the aggregate repairs exceed half the first cost of the structure or machine.

In the case of an asphalt or block pavement, annual repairs are usually very slight for a considerable term of years, the repairs often amounting to nothing at all. Let us assume that for K years there are no repairs and that then the repairs increase uniformly at the rate a for z years. Then the annual repairs (x) at any given year after the period of no repairs are given by this equation

$$x = az$$

And the total repairs are

$$R = \frac{xz}{2} = \frac{az^2}{2}$$

The average unit cost (u) of repairs per year is

$$u = \frac{C + R}{K + z}$$

$K + z$ being the total life (y).

Substituting for R its value $\frac{az^2}{2}$ we have

$$u = \frac{C + \frac{az^2}{2}}{K + z}$$

As before, solve for a minimum by differentiating and placing the first differential coefficient equal to zero. To do this, let

$$K + z = y$$

Then

$$u = \frac{C}{y} + \frac{az^2}{2y}$$

$$du = \frac{-Cdy}{y^2} + \frac{a}{2}\left(\frac{2yzdz - z^2dy}{y^2}\right)$$

But, since $K + z = y$, $dy = dz$, hence

$$du = \frac{-Cdy}{y^2} + \frac{a}{2}\left(\frac{2yzdy - z^2dy}{y^2}\right)$$

Then if we make $\frac{du}{dy} = 0$, we have

$$-C + \frac{a}{2}(2yz - z^2) = 0$$

$$-z^2 + 2yz = \frac{2C}{a}$$

But $y = K + z$, hence

$$-z^2 + 2(K + z)z = \frac{2C}{a}$$

$$z^2 + 2Kz = \frac{2C}{a}$$

$$z^2 + 2Kz + K^2 = \frac{2C}{a} + K^2$$

$$z + K = \sqrt{\frac{2C}{a} + K^2}$$

But $z + K$ is the economic life (y) of the pavement, hence expressed in words this formula becomes:

When a structure requires no repairs for a period of years (K), and then the repairs increase annually by a regular rate (a), the economic life (in years) of the structure is equal to the square root of the sum of (1) twice the first cost (in dollars) of the structure divided by the rate (a) and (2) the square of the number of years (K) of no repairs.

Thus if the period of no repairs (K) is ten years, and if the repairs then start and increase steadily at the annual of rate (a)

of 0.04 (or 4%) of the first cost, and if the first cost (c) is $1, we have:

$$\text{Economic life } (x+K) = \sqrt{\frac{200}{4}+100} = \sqrt{150} = 12.25$$

Hence the economic life would be 12.25 years, or only 2¼ years after the 10 year period of no repairs has expired.

In like manner formulas can be readily deduced for any other curves of repairs.

Having now before us a mathematically correct method of solving problems of this nature, it may be well to examine at least one of the incorrect solutions that have previously been published. In the following paragraphs will be found an erroneous method of attacking this problem.

Fallacious Formula For Determining When Increasing Repairs Justify Resurfacing a Pavement.—In 1906, Mr. George M. Tillson, Chief Engineer, Bureau of Highways, Brooklyn, New York City, read a paper* before the Mechanical and Engineering Section of the Franklin Institute, in which a method was given for solving a problem that often comes before highway engineers. Mr. Tillson said: "It is often desirable to know positively when the cost of repairing a pavement has become so great that it would be economical to relay the pavement. This can be determined by the same formula, as its result governs the cost of maintaining the pavement perpetually, so that when the annual repairs equal or exceed the perpetual annual cost, it is time to repave."

The formula to which he alludes is $A + CI + \frac{R}{N}$ = annual expense, in which

N = life of pavement in years.
C = first cost per square yard.
I = rate of interest.
A = amount to be paid in each year to create a sinking fund to equal C in N years.
R = total cost of repairs.

Mr. Tillson gives the following example:

"Take for instance an asphalt pavement and let N equal 15 years, C equal $1.50, I equal 0.035, and R equal $0.40. Then A will equal 0.0807 and the equation becomes $0.0807 + 0.0525 + 0.0267 = $0.1599; or if the street be repaved it will cost annually $0.16 till it is renewed. Consequently if the life of asphalt be correctly assumed at 15 years, it should not be repaved until the annual cost approaches $0.16 per sq. yd. Assuming the life to be 20 instead of 15 years and applying the formula as before, the annual cost will be reduced to $0.1356 per yard. The author believes this is the true scientific way in which to determine when an asphalt pavement, from an economical standpoint, should be relaid."

The problem that Mr. Tillson undertakes to solve is *when* a pave-

*The paper was reprinted in full in *Engineering-Contracting*, July 17, 1907.

ment should be relaid. Therefore the unknown quantity should be y, the number of years of economic life; but where does y appear in Mr. Tillson's equation? It really exists on *both* sides of the equation and is not transposed to one side before solving. If we study Mr. Tillson's method, we see that it amounts to this: His equation of condition is that when current repairs (r) for any given year equal "average annual cost," then it is time to renew the pavement. But we have seen that his assumed average "annual expense is $A + CI + \frac{R}{N}$. Now, calling the current repairs for any given year r, we have

$$r = A + CI + \frac{R}{N}.$$

This is the equation that we are to solve. Where is y, the number of years? If the repairs are increasing annually—and that is one of the conditions of this problem—r must be a function of y, so we have y on the left side of the equation. What is R? R is the total cost of repairs during the life y, so R is also a function of y. Hence the very thing we are trying to ascertain is *assumed* in the expression $\frac{R}{N}$.

Yet this is not the only place where it is assumed, for the amount to be paid annually into a sinking fund, A, is also a function of y. Hence one function of y is placed on the left side of the equation, and two functions of y and a constant are placed on the right side. We are then told that if we will juggle with the variable, y, until there is an equality, we have solved for y. Further comment on such misuse of mathematics appears to be unnecessary.

Straight Line Formula of Depreciation.—The most common way of determining the depreciated value of a machine, where appraisal of physical property is being made, is by the "straight line formula of depreciation." This consists simply in regarding each lost year of plant life as causing a depreciation proportionate to the entire loss of value at the end of its life. In other words, the rate of annual depreciation is 1 ÷ the total number of years of life. Thus, when the average life of a railway tie is 10 years, each year causes a depreciation of 1/10, or 10% of the first cost of the tie. At the end of 6 years it has lost 60%, and its depreciated value is 40%.

For some purposes of appraisal of present value of plant units, this method is, perhaps, satisfactory. Its simplicity appeals to all. But with increased knowledge as to life and cost of plant repairs, this simple method is likely to give way to the exact method of the Unit Cost Depreciation Formula (page 36).

It should be remembered that where a plant contains a large number of similar plant units of varying age—as in the case of all old railways—the average annual renewals are identically the same as the annual depreciation obtained by the straight line

formula. Thus if locomotives average a life of 25 years, annual depreciation by the straight line formula is 4%, and if the locomotives are of equal value but of different ages, annual renewals will be exactly 4% of the cost new.

As I have stated elsewhere, this condition makes it unnecessary to use a sinking fund table for determining depreciation, since renewals of entire plant units are regarded as identically the same as renewals of parts of each plant unit commonly called repairs.

The Bastard Straight Line Formula of Depreciation.—It is not an uncommon practice to "write off" a certain percentage for plant depreciation each year. When the amount written off is a fixed percentage of the first cost of the plant there is an application of the straight line formula of depreciation. However, it is the practice among many accountants to "write off" each year a percentage of the last year's "book value" of the plant. This produces a curve of "depreciated value of plant" that rapidly flattens out, and extends to infinity. There is certainly no logical defense possible for this method of estimating depreciated values.

Sinking Fund Formula of Depreciation.—According to this method it is assumed that the total depreciation of a machine or structure at any given age is the amount already accumulated in a sinking fund established for its redemption at the end of its life.

Table IV (page 15) gives the accumulation (a) of $1 for any number of years (n).

Table III (page 13) gives the annual deposit (p) in a sinking fund to redeem $1 at the end of the life of the machine, that is at the end of N years. Hence the accumulation in n years of an annual deposit of d will be

(16) $A = d \times a,$

d being taken for N years (life) from Table III,
a being taken for n years (age) from Table IV.

But, as previously shown in explaining these two tables,

$$a = \frac{1}{d^1},$$

d^1 being taken for n years from Table III. Hence,

$$A = \frac{d}{d^1}, \quad (17)$$

d being taken for N years (life) from Table III,
d^1 being taken for n years (age) from Table III.

Equation (16) is the most convenient for general use, but it is well to remember that equation (17) is equally applicable.

To illustrate by an example let us determine the depreciation of a railway tie 6 years of age, whose total life will be 10 years. If we assume a rate of interest of 4% we have by formula (17) and Table III

$$A = \frac{d}{d^1} = \frac{.0829}{.1508} = 55\% \text{ nearly,}$$

which is the percentage of depreciation or lost value.

Since the depreciation by this sinking fund formula is 55% of the first cost, the present value is 45%.

By the straight line formula the depreciation is 60% and the present value is 40%.

The same result (55% depreciation) is obtained with more expedition by the use of equation (16) and Tables III and IV.

Depreciation curves have been prepared from calculations made in this manner, and will be found at the end of the Waterworks Section of this book, for which consult the index under "Depreciation, Sinking Fund Curves."

The arguments upon which this method relies for support are two: (1) That the redemption of all perishable plant units should be provided for by sinking funds, and that, consequently, the accumulation in a sinking fund at any time represents the depreciation of the plant, which if delivered to a purchaser of the plant would recompense the purchaser in full for the plant depreciation. (2) That a sinking fund curve of increase, year by year, is analogous to the curve of increased cost of plant repairs.

The first argument looks sound, but is really fallacious. The purchaser is asked to accept a fund in place of an actual loss of value of the plant which may bear no relation to the fund at all.

The second argument is even more faulty, for by the wildest stretch of the imagination there can be found no logical relation between the annual cost of repairs and a sinking fund curve, since the one is the result of physical and chemical action, while the other is a function of rates of interest on capital.

We have already seen that the actual curves of plant unit repairs are not regularly ascending curves at all. And we have also seen that certain numerous classes of plant units have no appreciable repairs, save the final upleap in the curve which marks the entire renewal of that plant unit. It is, therefore, apparent that the sinking fund formula will not remain long popular after engineers have a clearer conception of the nature of plant repairs, and particularly after the fundamental principles of estimating unit costs of production are better understood.

In the following paragraphs will be found a determination of depreciation based upon the criterion of unit costs of production, which is the only criterion by which relative plant values can ever be accurately determined.

The Unit Cost of Depreciation Formula.—In selecting a name for the formula that I have deduced below, I have been somewhat at a loss to choose a title that would be descriptive of the principle involved, without being too cumbersome. For brevity it seems well to call it The Unit Cost Depreciation Formula.

The owner of a secondhand machine is entitled to such a price for it as will enable the purchaser to go on with its use and produce each unit of product at as low a cost as the average unit cost of production would be during the entire life of the machine.

This is but common equity, and needs no argument in its support. The equitable price thus arrived at is the depreciated value

of the machine. It will be noted that the criterion thus announced is essentially the same in principle as the criterion used in Problem I, for determining which of two new machines to select (page 17).

Adopting similar symbols we have:

N = annual average, number of units of product of machine during its entire life.

n = annual average number of units of product of the old machine during its remaining years of life.

C = first cost of a new machine.

c = depreciated value of old machine.

D = sinking fund annuity (Table III) to redeem first cost (C) of new machine at end of life.

d = sinking fund annuity (Table III) to redeem depreciated value (C) of old machine during its remaining term of years of life.

R = rate per cent of average annual repairs during entire life.

r = rate per cent of average annual repairs during remaining life.

$T = rc$ = total repairs during remaining life.

I = interest on capital.

O = average annual operating expense during entire life.

o = average annual operating expense during remaining life.

U = average unit cost of production during entire life.

u = average unit cost of production during remaining life.

Then

(18) $$U = \frac{O + RC + DC + IC}{N}.$$

(19) $$u = \frac{o + rc + dc + Ic}{n}.$$

But $rc = T$, hence

(20) $$u = \frac{o + T + dc + Ic}{n}.$$

According to the principle that U should equal u, we have

(21) $$\frac{O + RC + DC + IC}{N} = \frac{o + T + dc + Ic}{n}.$$

In all ordinary cases, $O = o$, and $N = n$, hence

(22) $$RC + DC + IC = o + T + dc + Ic.$$

Therefore,

(23) $$c = \frac{C(R + D + I) - T}{d + I}.$$

Formula (23) gives the depreciated value of a secondhand machine or structure. If it is desired to express this depreciated value as a percentage of the first cost C, we have

(24) $$\frac{c}{C} = \frac{(R + D + I) - T}{d + I}.$$

Formula (24) is our unit cost depreciation formula.

If repairs during the entire life are nominal in amount, then both R and T vanish, and we have

$$(25) \quad \frac{c}{C} = \frac{D+I}{d+I}.$$

Formula (25) is the one to apply to railway ties, water pipe, and other plant units that have no appreciable current repairs.

For contrast with the sinking fund formula, let us find the depreciated value of a railway tie 6 years old, whose life is 10 years, interest being 4%.

Table III (page 13) gives:

$D = 0.0833$ for 10 years, and 4%.
$d = 0.1508$ for 6 years, and 4%.

Then according to equation (25) we have

$$\frac{c}{C} = \frac{8.33+4}{15.08+4} = \frac{12.33}{19.08} = 64.5\%.$$

We have seen that the sinking fund formula gives a depreciated value of 45%, and that the straight line formula gives 40%, with the same data as to life, age, etc.

Contrast formula (25) with formula (17), and it will be seen that the sinking fund formula differs in not having I added to both numerator and denominator.

Contrast formula (25) with formula (17), and it will be seen that the sinking fund formula errs to an even greater extent, for it makes no rational provision for consideration of the *actual* repairs during the whole life and the remaining life of the machine.

So far as I know, these formulas (24) and (25)—unit cost depreciation formulas—have never been deduced before. Formula (25) lends itself as readily as the sinking fund formula to being platted as a curve. Formula (24) can also be expressed as a curve, when the *actual* rates of repairs are known, but it does not lend itself to any guesswork, which, after all, is a real merit. There has been too much guessing as to rates of repairs.

Physical Property Valuations.—As a result of the growing control that governments are exercising over public service corporations, as well as because of the tendency to place all property values on a scientific basis for taxation, there have been many recent appraisals of the physical, or tangible, property of railways, lighting companies, etc. Many more such valuations will be made in coming years, and will require the constant services of many engineers in keeping the valuations up to date. Moreover, I am inclined to believe that the valuation of the physical property of all large corporations will eventuallly be made by governments, if for no other reason than to protect stockholders from unscrupulous company officials, who by insufficient maintenance of plants can make net earnings seem to be larger than they really are, and thus inflate stock values for a time, only to reverse the process and cause a slump. No scientific expenditure for proper plant maintenance is possible without a knowledge both of the character of the plant and the service it is rendering but of

the amounts of capital invested in the various plant units. This is tantamount to saying that no one can judge accurately from reports of annual maintenance expenditures whether a large plant is being properly maintained unless a detailed appraisal of the physical property is at hand. This alone would justify every railway and every large manufacturing company in having a physical appraisal made and kept up to date, for its own purposes. Some, in fact, do, but they are woefully in the minority as yet.

A physical appraisal involves ascertaining all unit quantities of construction, and the number of plant units of each class, to which standard present prices are applied. This gives the *cost of reproduction new.*

The next step is to ascertain the average age of the units of each class, for the purpose of estimating *depreciated value,* or, as it is more often called, *present value.* We have just seen that three formulas are now available for this purpose: (1) The Straight Line Depreciation Formula; (2) the Sinking Fund Depreciation Formula; and (3), one that I now submit for the consideration of appraising engineers, the Unit Cost Depreciation Formula.

In the Railway Section of this book I have discussed the proper method of arriving at the average age of plant units of the same kind, but differing in first cost. (See the index under "Appraisal, Railways"; also see "Appraisal, Waterworks).")

Going Concern Value.—In addition to the first cost of a plant, including the interest on the investment during construction, there is another sort of expense that should properly be included in arriving at the cost of the plant to its owners, and that is the cost of getting the business.

For some years after a plant is put in operation, it frequently is run at an actual loss, until its products become favorably known to the public, or until the development of its tributary population supplies the business.

The early losses in operating a plant should usually be regarded as actual expenditures in developing the business, and should be figured at compound interest up to the time that there ceases to be a loss from operation.

And now comes a very important point to bear in mind when determining these operating losses, namely that during the early years of a plant operating expenses (including maintenance in the term) are below normal. This results from the fact that new machinery requires little or no repairs. In equity, therefore, not the actual repairs should be considered but the annual sinking fund deposit necessary to provide for the excess repairs that must be borne in later years.

Having thus determined the full theoretical maintenance (actual plus proper annual allowance for sub-normal repairs), and operating expense, there comes a time when there ceases to be a loss from operation and when the earnings also suffice to pay the interest on the bonds, or the capital invested. Still, money continues to be expended in advertising and in soliciting new business. This

money is also an element of cost in establishing the business, and, as such, is to be regarded as a part of the cost of the plant and its business.

The sum of the money lost at first in operating the plant, and the money spent in advertising, soliciting business, etc., may be called the going concern value of the plant, which should certainly be added to its physical value.

A further discussion of this subject appears at the end of the Waterworks Section. Consult the index under "Value, Going Concern."

Commercial Valuations.—The method of valuing an existing business is one of comparative simplicity, unless there is doubt as to physical condition of the plant. In which case a physical valuation of the plant may be needed to determine what the excess cost of repairs is likely to be due to a run-down condition.

When this does not enter the problem, the question is simply one of ascertaining the net earnings and of capitalizing them at a rate of interest which judgment in such matters dictates as being reasonable. If the business is large and long established, the rate of interest used in capitalization may be as low as 5%, provided "net earnings" are regarded as the remainder after deducting operating expense, maintenance and interest on the investment (= interest on bonds).

This is as low a basis as is apt to be used, unless the curve of growth of the business is such as to warrant favorable speculation as to its future, or a discounting of the future by assuming a lower rate of interest as a basis for capitalization.

When a business is small and subject to fierce competition of capable rivals, and is dependent for its present success largely upon one or more individuals, the rate used in capitalizing its net earnings should be very high. In this connection it may be well to caution the young engineer against being deceived as to the operating expense of a small business. The owner of such a business frequently draws only a small salary, and looks to the dividends or profits for his real salary. When he has sold the business, it will probably be necessary to hire a manager of ability equal to that of the owner, and to pay him a much higher salary than the owner drew.

It is a curious fact that this consideration has escaped the attention of not a few men who have appraised the value of small business concerns. One celebrated English promoter made several fortunes by capitalizing comparatively small business concerns on net earnings shown truthfully in their books, but which did not show that the mental equal of the old owner of the business could not be hired except for a very large salary.

An interesting discussion of the commercial valuation of railways will be found in Bulletin 21, Department of Commerce and Labor, Bureau of the Census, entitled "Commercial Valuation of Railway Operating Property in the United States, 1904."

Prof. Henry C. Adams, Prof. B. H. Meyer, and Mr. William J

Meyers give many valuable data in the course of the discussions in the Bulletin No. 21, which contains nearly 90 pages.

From a great array of railway statistics, Mr. William J. Meyers concluded that railway bonds averaged a return of 3.793% on their market price, and that railway stocks averaged a return of 4.918% on their market price. He says: "Combining the figures for shareholders' interests with those for the funded debt (bonds) we get as the mean rate of annual return on all securities 4.256%, which is thus indicated as the proper rate to be used in capitalizing net earnings from operation (diminished by taxes) in order to arrive at the value of the security holders' interests in the operating property."

How to Prepare Estimates and Bids.—In estimating a unit price for any kind of work, contractors often place too much reliance on published prices for similar work. There are seven serious sources of error in so doing: (1) The conditions may vary greatly in places but a few miles apart; (2) rates of wages often vary widely, being, for example, higher in large cities than in small cities or in the country; (3) specifications and the interpretations of identical specification clauses by different engineers vary greatly; (4) contractors inexperienced in the particular work in question often have bid prices altogether too low; (5) the bidding prices may be purposely unbalanced, being too high on certain items and too low on others; (6) a unit price that is fair for a large job is generally too low for a small job; (7) a contractor already equipped with a plant can often afford to bid lower than the contractors not so equipped.

While previous bidding prices should be used as a guide, they should never be relied upon implicitly if the work is of any considerable magnitude. Each item should be estimated in detail, and this estimating should be done systematically to avoid some serious omission. The cost of any item of work may be divided into five parts:

1. Development expenses.
2. Plant expense and supplies.
3. Materials.
4. Labor.
5. Superintendence and general expense (overhead charges).

Development expense includes the cost of making roads, delivering and installing the plant, draining the site of the work, salaries of foremen and others on the idle list pending the beginning of work, and all expenses involved in getting ready to build the structure. On small jobs this item of development expense is often a very large percentage of the total cost; and on large jobs it seldom can be neglected in estimating probable unit costs.

Development expense has to be estimated for each particular job, by securing freight rates or estimates for carting, etc. In some cases it includes temporary road building, installing pipes for water supply, etc.

Plant expense includes interest, repairs, depreciation and in-

surance on all tools, machines, buildings, stored materials, trestles, falsework; and supplies include fuel, oil, etc.

Materials include only such materials as actually go into the finished structure, and the wastage of materials due to breakage in handling or sawing and shaping. The cost of materials includes freight and hauling to the site of work.

Labor includes all skilled and common labor, except superintendents, clerks and office men.

Superintendence and general expense includes foremen, managers, timekeepers, watchmen, bookkeepers, supply clerks, rents, taxes, traveling and entertaining expenses, stationery, etc.

To the experinced contractor an enumeration of these items may seem unnecessary, but it is indeed surprising to see how often inexperienced contractors err through failure to consider all of these items. Engineers, and not always young engineers, are prone to omit development and plant expenses, either in whole or in part, from their estimates of cost.

Returning to the subject of deciding upon bidding prices, make it a practice always to check the quantities given in the bidding sheet as far as possible. If the contract is a large one, or the work is such that you cannot personally do all the checking, employ an engineer to do so. It is astonishing to note the number of errors, typographically or otherwise made, that creep into quantity sheets. An error of transposition is not uncommon; thus, the engineer may have correctly determined that there are 3,000 cu. yds. of embankment and 1,200 cu. yds. of riprap, but in the bidding sheet the quantities may be transposed so as to read, 1,200 cu. yds. of embankment and 3,000 cu. yds. of riprap. In looking over the quantities, therefore, always ask yourself whether each quantity "looks about right," or not. A shrewd contractor will thus discover errors that a whole staff of engineers have overlooked. Whenever you see a small, and what appears to be an arbitrary quantity, like 10 cu. yds. of concrete or 50 cu. yds. of rock excavation, look carefully over the plans and specifications to discover if possible where this quantity is shown in detail. If it cannot be found that the quantity has been actually measured, it is safe to assume that it has been guessed at, and that in consequence it may subsequently prove to be an under-estimate. Bid liberally on such items, but bid not too liberally. More contractors, otherwise shrewd, than one would expect to see make the error of bidding unreasonably high on such small items. The result sometimes is that their bids are rejected because they are "unbalanced"; or, if accepted, and later it is found that a larger quantity of the unbalanced item exists, the engineers may either change the plans or relet the work covering that item. Set it down that seldom is it good business policy to bid an unreasonably high price on any item even on public works contracts, and it never is wise to do so on private contracts. Even though the item is small, and the cost of putting up a plant to perform the work is large, still bid only a little higher price on the item than you would bid if it

were many times larger, and distribute the estimated cost of plant over the other items.

A Schedule of Items of Cost.—In preparing an estimate of unit cost there is always danger of omitting some important item. To avoid such an omission I find it desirable to compare my estimates with a schedule of items, such as follows:

1. Cost of temporary roadways
2. Cost of right of way through farms, etc.
3. Cost of clearing and grubbing the site.
4. Cost of snow removal and draining the site.
5. Cost of the site.
6. Cost of sheds, barns, offices, etc.
7. Cost of delivering and installing plant.
8. Cost of supplies, including explosives, water, fuel, oil, etc.
9. Plant, interest, depreciation, and repairs.
10. Cost of shifting plant units from one point of attack to another, including lost time of workmen waiting during the shifting.
11. Cost of trestles, falsework, bracing, forms and temporary supports.
12. Quarry rent, sand pit rent, timber stumpage, etc.
13. Cost of materials f. o. b. for a unit of the structure, including wastage.
14. Freight on materials.
15. Cost of unloading, hauling and storing of materials.
16. Cost of delivery and re-handling materials until at the place to be used.
17. Labor of handling, shaping and placing materials, and all operating labor.
18. Foremen's salaries.
19. Salaries of watchmen, timekeepers, clerks, bookkeepers, etc.
20. Office and traveling expenses.
21. Interest on cash capital other than plant.
22. Taxes, licenses and insurance of property.
23. Insurance of workmen and the public against accident.
24. Premium paid to bondsmen or surety company for bond required.
25. Advertising, legal expense, charity.
26. Discount on warrants, notes or other paper payments for work done.
27. Riot protection and detective work.
28. Sanitation.
29. Housing plant during winter.
30. Providing waterproof garments.
31. Engineering.
32. Percentage added to materials and percentage added to labor, to cover contingencies.
33. Percentage for profit.

Plant Expense.—Plant expense is commonly underestimated. First it is necessary to consider the time limit allowed for the

work. Then a plant must be figured upon that will perform the work at least 20% within the time limit, making also liberal allowances for bad weather delays, as well as for delays in delivering and installing the plant, and delays due to breakdowns.

Use with great caution the figures of output given in most catalogs; they are almost invariably based upon ideal conditions, and not infrequently are wholly deceptive. Even where the output of a machine is correctly stated, remember that such an output may not be possible in your case, due to inability to get materials to the machine or away from it. Consider always the limiting factor. A derrick, for example, may be able to handle 200 cu. yds. a day, but if it serves a few men working in a confined space, its actual output may not be 30 cu. yds. Time and again this self-evident fact has not been evident to the inexperienced man.

To give another example, suppose the work is rock excavation. Do not guess at the number of rock-drills required; but estimate the probable spacing of the drill holes in the given kind of rock and from this calculate the number of cubic yards of rock each drill will break daily on a basis of, say, 50 ft. of hole drilled per machine per shift. Knowing the time limit, compute the number of drills required; and, knowing the number of drills, compute the boiler power required. Guess at nothing. If you have no other data, secure, by letter, some estimates of output from the large and old manufacturing firms, whose estimates are frequently very close to the truth.

Allow liberally for plant that is idle during shop repairs. On railways, for example, 8 to 12% of the total number of locomotives are constantly in the shop undergoing repairs.

Having liberally estimated the size and kind of plant required, and having secured quotations on the plant, charge the full cost of the plant up to the job to be done, and determine how many cents per yard, or per other units involved, are thus chargeable to first cost of plant. This will give a maximum charge, and it is well to know the worst. But if the full cost of a plant is charged to a small job, some other contractor will probably get the work. Go, therefore, to a dealer in second-hand machinery, and ask him to name a fair price on a second-hand plant such as yours will be when you are through with it. If you can secure a tentative bid on the machinery, you will have a fairly reliable estimate of the salvage value. In most cases you can form some estimate of the salvage value, by finding what second-hand plants are selling for. If you are still afraid that your charge for depreciation will be so high as to lose the job, there is left just one safe way of estimating, namely, to secure a rental quotation. There are many firms who make a business of renting contracting plants, and such a plant as is wanted can usually be rented for a daily or monthly price that includes ordinary wear and tear. The longer the plant is to be used the lower the daily rate of rent, therefore be careful to secure a sliding scale lease. A hoisting engine and boiler may be rented for, say, $2 a day, if the period is to be 30 days; but, for each added

30 days, there should be a reduction in the rate, down to, say, $1, beyond which no further reduction is given. The reason why such a sliding scale can be secured is briefly this:

The season for contract work is usually limited; road work, for example, is limited to the summer and fall months. Most of the contracts are awarded at an early date, so that if a plant remains unrented well into the season, the chance of renting it falls off rapidly. Periods of idleness between times of rental soon cut down the net income from a plant, yet interest on the investment goes on uninterruptedly. If these periods of idleness can be reduced the owner of a plant can afford to accept a lower per diem rate of rental, yet be a gainer at the end of the year.

Then, too, there are some seasons when contractors and their plants are abundant, and work is scarce. The revenues from such plants are then correspondingly small.

I have found that a roadmaking plant does not average 100 days actually worked per year. A 10-ton steam roller costs, say, $2,500; and, if interest is charged at 6% per annum, we have $150 to be distributed over 100 days—not over 365 days, as many engineers have done.

Depreciation, of course, does not go on as rapidly when a plant is idle as when working, provided the plant is properly housed and cared for; but the housing and the care cost money. Moreover, many kinds of machines become obsolete in a few years, so that depreciation cannot be said wholly to cease while the plant is idle. All the annual repairs and depreciation and all the cost of housing and caring for the plant should be distributed over the average number of days actually worked. If, on a 10-ton steam roller, the annual depreciation is $200, we have $200 ÷ 100, or $2 per day worked; and if we add to this the $1.50 per day charged to interest, we have a total of $3.50 per day worked. Now, such a charge should be made by the contractor even where he uses his own roller.

It may be asked why the interest, repairs and depreciation are distributed over the days actually worked. The answer is that the output of the plant is usually estimated as so and so many units per day, and that, in consequence, all costs should be reduced to the same basis.

In such states as New York there are only about 8 months of the year, and about 21 or 22 days per month, suitable for economic outdoor work of the class of earth excavation. Weather records will enable any one to predict with reasonable accuracy the number of working days per year in any locality.

Cost of Superintendence and General Expense.—The cost of foremanship on contract work seldom exceeds 15% of the cost of labor, and it seldom runs much below 5%. If one must guess, perhaps 10% is a fair average. These percentages include the salaries of foremen only. The salaries of general superintendents and office men, and all office expenses are preferably called "general expenses" or "fixed expenses." General expenses seldom amount to less than 4%, and on small, intermittent job work they may run much higher.

In estimating supervision by the percentage method, care should be taken to exclude the cost of materials and to base the estimate upon the labor only. As an illustration: The General Expenses for the average American railway are 3.9% of the total expense of operation (including maintenance), distributed as follows:

	Per cent.
Salaries of general officers	0.826
Salaries of clerks and attendants	1.372
General office expenses and supplies	0.263
Insurance	0.481
Law expenses	0.452
Stationery and printing (general office)	0.182
Other expenses	0.300
Total general expense	3.876

This does not include superintendence of "maintenance of way," or of "maintenance of equipment," nor of "conducting transportation." The first of these items is not reported separately, but we shall assume it to be the same as maintenance of equipment since the gross expense for maintenance of way is practically the same as for maintenance of equipment.

	Per cent.
Maintenance of way (assumed)	0.561
Maintenance of equipment	0.561
Conducting transportation	1.776
	2.898

This gives a total of practically 3% for superintendence and 3% more for general expense if we exclude "insurance" and "law expense" from general expense. But this combined 6% is 6% of the gross operating and maintenance expense, only 60% of which is labor, the remaining 40% being for materials, supplies, etc. Hence, the percentage based on labor alone is 10% for general expense and superintendence, about equally divided between the two. For further study of these, see the Railway Section.

For data on the expense of engineering supervision of public works, see the Surveying and Engineering Section.

Throughout this book are numerous data on costs of supervision, for which consult the index under Supervision. Also consult the index under General Expense.

Percentage to Allow for Contingencies.—After estimating the probable cost of every item of work as closely as possible, including superintendence and general expenses, a percentage should generally be added for contingencies. A very common allowance is 10%; but no such rough guessing is indulged in by either a careful engineer or by an experienced contractor.

Contingencies is an item used to insure against oversights and ignorance. On work where sub-contracts can be let at once for the materials, there is practically no risk taken on materials, hence there is no justification, on the part of the contractor, in making an allowance to cover contingencies on materials. The engineer who designs a structure may be justified in making such an allowance to cover possible bills for "extras," but not otherwise. On the other hand, it is often wise to make an allowance to cover pos-

sible inefficiency of laborers, or possible strikes, or possible rise in rates of wages; for, after estimating the average cost of labor on a given structure, there is always some risk of exceeding the average, for some unforeseen reason. On large jobs both the designing engineer and the contractor are justified in adding from 5 to 20% to *estimated labor costs* to cover contingencies. If the price of materials has been steadily rising, then a study should be made of price curves extending over several years in order that some rational allowance may be made for the probable rise in prices of materials before they can be sub-contracted for. If, on the other hand, prices are on the downward curve, a contractor may feel justified in bidding lower than he otherwise would. The best way to arrive at an allowance for contingencies is to keep a full record of the estimated cost of each item of work, and subsequently compare it with the actual cost. In this way it will be found that there is seldom a job on which every item of cost can be accurately predicted.

Percentage to Allow for Profits.—The common method of adding uniformly 10 or 15% for profits is open to serious objections, among which are the following: (1) The percentage to add for profits on materials should usually be less than the percentage to add for profits on labor, particularly when profits and contingencies are lumped together; (2) the time element and the size of the job should always be factors in considering profits, for profits are, strictly speaking, the salaries of the contractors; (3) the number of dollars' worth of contract work that can be secured and handled each average year must be considered, for the reason just given; (4) the percentage for profits is often made to include interest on plant and on cash capital invested, and, if so, there is added reason for not using a uniform percentage like 15%.

That there is need of calling attention to these elementary principles is apparent when one notes erroneous statements found in many text-books.

On materials, such as brick, timber and steel, that can be bought by sub-contract immediately after the award of the main contract, one may estimate a low profit, say, 10 or 15%; but on labor the profit should usually range from 15 to 25%, or even higher if contingencies are included in the percentage allowed for profits.

On contract work that can be done only during a few months of the year, and especially on work requiring a large investment in plant, such for example as macadam road work, the percentage of profits must usually be above the average of the percentage on work that extends over a longer period. If engineers fully realized the importance of this fact they would be at more pains to award all highway contracts early in the spring of the year, so that a longer season would be available than is now the case.

Causes of Underestimates.—Engineers have been said to be men who can be relied upon in every respect save one—ability to predict the cost of work. The reasons why engineers' estimates have so often been unreliable may be enumerated as follows:

1. Students of engineering are seldom trained in the art of cost estimating, but left to acquire that art haphazard after graduation.

2. Articles descriptive of engineering structures seldom contain an analysis of the unit costs.

3. A subsurface survey is frequently not made; and, as a consequence, unexpected materials are encountered in excavating.

4. A study of the sources of local materials, their suitability for the work, and their unit cost delivered, is often not made; and, as a result, specifications are frequently drawn that cannot be lived up to except by importing materials at great expense.

5. The cost of clearing, and draining the work is often underestimated, or ignored entirely.

6. The cost of temporary bracing, support, roadways and development expenses are frequently underestimated or omitted.

7. Delays due to bad weather, and delays incident to the shifting of plant from place to place are often not considered.

8. Interest and depreciation of plant, and the percentage for profits, are usually underestimated.

9. Inadequate allowance is made for superintendence and general expense.

10. The cost of inspection and engineering may be underestimated.

11. Legal expenses due to the abandonment of the work by a contractor, or due to suits brought by those who claim damages to life, limb or property, are generally not allowed for.

12. Changes in the alinement or in the design, made after contracts have been awarded, may result in large claims for extra compensation.

13. Omissions due to carelessness or ignorance of subordinates in the engineering staff may result in further claims for extras.

14. Rates of wages and prices of materials may rise; and, if the work is large, the work itself may be the cause of such increases.

15. When high wages are due to scarcity of men, an "independence" is bred in the workmen which decreases their efficiency.

16. A large number of competent foremen frequently can not be secured for a large work, resulting in decreased efficiency of workmen.

17. If an estimate is based upon previous contract prices there is grave danger of error, due to change in conditions, unbalanced bids, etc.

18. If unit prices are estimated before the specifications are drawn, the specification requirements may be made such as greatly to increase the cost of important items.

19. Limiting competition by the drawing of unfair, or indefinite specifications, is a common cause of high bidding prices. Severe interpretation of indefinite clauses often causes failure of contracting firms, and the history of such failures operates to limit subsequent competition, and raise prices.

20. Contractors may combine, especially where the work is let in very large contracts, and raise prices.

Indexing Contract Prices.—In order to fix a bidding price on the proposed work, if no actual records of similar work are available, it is customary to hunt up bidding prices on similar work, strike an

average, bid a little below the average—and trust to luck. To make this process less of a gamble, it is wise to secure back volumes of engineering periodicals, and make a scrap book using the pages of the journal that relate to contract prices. Then as the scrap book should be indexed, a word as to indexing may be of assistance. There should be heads corresponding to the items usually found in bidding sheets, as follows: Asphalt Pavement, Ballast, Bolts and Spikes, Brick Masonry, Brick Sewers, Brick Paving, Bridges, Castings, Catch-basins, Cement, Clearing and Grubbing, Concrete, Curbs, Earth Excavation, Embankment, Flagging, Flush-tanks, Gravel, Gutter, Hydrants, Iron, Lampposts, Lead, Macadam, Manholes, Masonry (stone only, and not brick or concrete), Piles, Pipe Sewers, Puddle, Railing, Riprap, Rock Excavation, Sidewalks, Sodding, Specials, Steel, Stone, Timber, Tracklaying, Valves, Water Pipe, etc. As far as possible select headings that denote the kind of material used in the structure; but where this cannot be done without confusion select the name of the structure as it ordinarily appears in bidding sheets. Do not, as a rule, use such headings as the following: Abutments, Filling, Dredged Material, Foundation, Vitrified Brick Paving, etc. An abutment often contains piling, concrete and cut stone masonry, and in using the index it may not occur to you to look under abutment when looking up prices on concrete.

Having decided upon headings, cut up a lot of paper strips about an inch wide and four inches long, and proceed to go through the printed pages to be indexed. When a bid on Concrete is found, write on one of these slips, "Concrete, pavement foundation, p. 80." Throw the slips aside as the index entries are made; and, after a volume has been indexed, assort the slips alphabetically, and have a typewritten index copied from them. Simple as this method is, the inexperienced man is not likely to think of it, and failing to think of it he will look upon the job of indexing as being so great a task that in all probability no index will be made. Indexes published at the end of the year by the technical journals are, as a rule, of no value to the contractor; furthermore, the current issues of construction news should be indexed as fast as received. Especial care should be taken to index classes of work that are out of the ordinary, for whenever bids must be submitted on similar work no better guide than previous contract prices is apt to be found.

In recording bidding prices, it is well to record not only the lowest bid, but the average of all bids, stating the number of bidders.

In judging the reasonableness of a bidding price, it is of great assistance to know the experience of the bidder on the particular class of work in question. Hence a knowledge of the history of contractors is a decided aid.

Care should be taken to examine not merely a contractor's bid upon the one item that is under consideration, but his bidding prices on all the items, to judge whether or not he may have unbalanced his bid to conceal his judgment as to a fair price for each item.

Unbalanced Bids.—A bid is said to be unbalanced when too high a price is purposely bid upon one or more items, accompanied by an offsetting low price on one or more of the remaining items. Thus, if a fair bidding price for earth excavation is 25 cts. per cu. yd., and for rock, $1.00 per cu. yd., the following forms an example of a bid that is balanced, and one that is unbalanced:

BALANCED BID.

1,000 cu. yds. rock, at $1.00	$1,000
20,000 cu. yds. earth, at $0.25	5,000
Total	$6,000

UNBALANCED BID.

1,000 cu. yds. rock, at $2.00	$2,000
20,000 cu. yds. earth, at $0.20	4,000
Total	$6,000

It will be seen that the total bid, $6,000, is the same in both cases. In the second case, however, the $2 bid on rock is altogether too high, and the 20-ct. bid on earth is too low, hence the bid is unbalanced. The objects of unbalancing bids may be three: (1) To secure an abnormally high profit on any item the yardage (or quantity) of which is likely to be increased after the contract has been awarded; (2) to secure a large profit on the items of work that must be done first, thus skimming the cream of the contract in the very beginning; (3) to conceal from engineers and from competitors what each item of work is actually worth.

To prevent the unbalancing of bids, engineers resort to various expedients, among which are the following: (1) Insertion of a clause in the "invitation to bidders" warning them that an unbalanced bid will cause the rejection of the bid; (2) requiring a lump-sum bid on the work; (3) publishing the engineer's schedule of items and an estimated price for each item, then requiring either (a) that each contractor shall bid a uniform percentage on all the items, or (b) that the contractor shall bid his own price on each item, no unit price being in excess of a certain percentage of the engineer's estimated unit price. The first of these two methods is called the "percentage method of bidding."

A fourth method of preventing unbalancing of bids on small items likely to be increased in quantity may be suggested. It would consist in naming a definite unit price that will be paid on each of the minor items, and leaving the contractor free to bid his own prices on the other items.

The greatest danger from an unbalanced bid lies in subsequent change of quantities. Suppose that in the above given example, actual work discloses that a far greater quantity of rock exists than the 1,000 cu. yds. given in the bidding sheet. Suppose the actual quantities in the final estimate are reversed, and that there are 20,000 cu. yds. of rock and 1,000 cu. yds. of earth. We then have these results:

BALANCED BID.

20,000 cu. yds. rock, at $1.00	$20,000
1,000 cu. yds. earth, at $0.25	250
Total	$20,250

UNBALANCED BID.

20,000 cu. yds. rock, at $2.00	$40,000
1,000 cu. yds. earth, at $0.20	200
Total	$40,200

We see that if the unbalanced bid is accepted the work costs in the end almost twice as much as it would have cost had the balanced bid been accepted; yet the two bids were the same ($6,000), according to the preliminary estimate.

It rarely happens that such an extreme case as this occurs in practice, although I have known several quite as bad. The principle, however, is best illustrated by an extreme example.

It is common practice among paving contractors in many cities to unbalance their bids for the sake of concealing their estimates of actual worth; as, for example, among asphalt paving companies. Bidding prices must, therefore, be looked upon with suspicion always, especially when used as guides for estimating.

An unbalanced bid is a two-edged sword. It may actually ruin the contractor who makes it, if it happens that he has erred and that the quantities on which he has bid too low are greatly increased, without a corresponding increase in the quantities on which he has bid high. Like all tricky practices, it is a dangerous one.

Surety Company Bonds.—It is becoming more and more the practice to require contractors to furnish the bonds of a surety company rather than the bonds of individuals for the faithful performance of the work. This is not only good public policy, but it is in the best interests of contractors themselves.

No man should put in jeopardy the property of his friends by asking them to go on his bonds for a contract. It matters not how sure he may be of himself and of his ability to execute the work at a profit, for he should bear in mind that a strike beyond his control may upset all calculations. Furthermore, a young contractor's own estimate of himself is apt to have an optimistic tint, to say the least. A surety company should be consulted, and it is well to go to such a company at first with only a small contract for which bondsmen are desired. Be prepared to give them in detail your experience and your financial resources, exaggerating neither; for, in case of subsequent failure, criminal proceedings may be brought against a man who has misrepresented his resources. If you have but little cash capital, frankly say so, but be prepared to show in detail how you propose doing the work with the funds available. Suppose you expect to have a $5,400 earth work job to do; that you will have 12 weeks in which to do it, with two weeks margin for delays, etc.; and that payments of 85 per cent of the estimated value of the work done are to be made monthly, and you purpose beginning the work the middle of the month. You estimate the work to cost $4,800, hence your weekly pay-roll will be $400 if the work is done in 12 weeks. You are to pay your men every two weeks, hence you need only $800 in cash to carry you until the first of the month, and as your contract calls for the monthly payment to be made the 10th day of the month, you can

count upon receiving $765 (85% of one-sixth of $5,400) in time to apply on the next pay roll. Your cash capital to start with is $1,800, or practically twice as much cash as will carry the work, in case there are no unforeseen delays, and in case you have not underestimated its cost. If you are able to persuade the surety company's representative that your estimate of actual cost of the work is reliable there should be no difficulty in securing their agreement to act as your bondsmen.

Reasons Why Contract Work Is the Most Economic Method of Doing Public Work.—There are two methods of doing public work: (1) The day labor, or government force, method; and (2) the contract method.

By the day labor method the government (county, town, city, county, city or federal) hires the workmen and directs their work. The alleged advantages of this method are:

1. It saves the contractor's profits.
2. It insures better work.
3. It avoids lawsuits.
4. It permits beginning work without a complete survey or plans, and thus hastens completion.
5. It gives employment to local citizens and keeps all the money at home.

As to the first alleged advantage there is an evident fallacy, for the attitude is one of regarding a contractor's profit as something other than a recompense for his skilled services. A contractor's profit is his compensation for services—nothing else. Hence when a contractor is dispensed with there must be a substitution of some one in his place to render the service of manager. It is often urged that since a government must supervise a contractor, to see that he does his work properly, it is really paying twice for supervision of the workmen. This, again, is fallacious for two reasons: (1) Supervision that is merely inspection is far cheaper than supervision that consists in managing men; (2) there should be inspection of work done by government employes, and, in my opinion, there is need of a much more rigorous and expensive inspection of their work than of work done by contract. Government employes are prone to depart from plans and specifications, often for the sole purpose of partly concealing the otherwise high costs that would become evident to all. It is the verdict, too, of practically all unbiased and experienced engineers that day labor work does not deliver as good quality of product as contract work. This answers argument 2.

As to argument 3, avoidance of lawsuits, we have an advantage that is certainly well founded. It does, but the average cost of lawsuits is so small a fraction of the total cost of construction work done by contract as to be unworthy of serious consideration. Moreover *lawsuits of this kind are almost invariably the result either of ambiguous specifications or of changing plans without equitable provision for payment arising from a change.* The remedy for this condition is not an entire abandonment of the contract system. As well might a surgeon cut off a man's legs be-

cause he squints. Lawsuits are avoidable and are avoided by the best engineers, for they perfect their plans before securing bids, their specifications are so framed as to provide perfectly for any changes, and, finally, *they never vitiate the written contract by departing one iota from its provisions.*

There are many so called "contractors' lawyers" in our larger cities, who are little else than skilled thieves in league with other thieves who get contracts. That these "contractors' lawyers" are able to make money for themselves and their clients is due almost entirely to the fact that engineers do not adhere rigorously to the specifications. For if a lawyer can prove that the specifications have been violated, even to no great extent, no contract exists, and there is ground for recovery of profits *quantum meruit*—as much as he deserved. This leads to expert testimony as to profits reasonably to be expected, and this usually leads to a verdict that is a compromise between the two extremes of testimony. Railways and private corporations are not so frequently afflicted with lawsuits because their policy is not to award contracts to contractors of the kind above mentioned. Public officials should also be empowered to reject bids from contractors who have a record as litigants, as well as from contractors who can not show sufficient experience and financial resources. A remedy for an evil is always preferable to the wholesale execution of innocent and guilty alike.

As to the alleged advantage of beginning work before plans are complete, I deny it to be an advantage. Innumerable increases in estimated cost of public work are due to this very thing—beginning work in advance of the fullest study of conditions.

Finally, as to employment of local citizens, this is precisely what a contractor does. But—and mark well the difference—a contractor does not make his organization an old men's home or an asylum for the afflicted. The place for such is not on a piece of construction where they not only take up valuable room but act as the worst sort of examples for the young, ambitious and capable workmen.

Now let us consider briefly why the contract system of doing public work is advantageous:

1. The contractor is paid for his services by his profits, which is in strict accord with the fundamental law of management. (See page 74).

2. He is free to pay his superintendents according to his judgment of their worth, and all his employes according to the bonus system.

3. The contractor is a manager appointed by no official, elected by no "voice of the people" (which is more often the voice of ignorance than "the voice of God"), selected by no civil service examination. He has become a manager by virtue of the law of the survival of the fittest, as determined by strife for excellence. When this method of selection is to be improved upon by men, it may be well to consult the Deity who established it.

4. A "public servant" is a servant without a master. He may have a "boss" who acts as a proxy for the master, but the master,

the owner of the house—where is he? He is the butcher, the baker, the candlestick maker, a thousand, a million, or, maybe, a hundred million of him scattered across all the acres between two seas. He never is seen by the servant, nor felt, nor heard. This master who foots the bills of those who boost the bills never approaches an indolent superintendent and lays a hand upon his shoulder, nor says: See here, my man, unless this ends, you end this.

A contractor is a master, and the "servants" see and hear him. He is tangible; no vague rich Uncle Sam off somewhere, but a living personality on the job; not a genial personality, with lots of money to throw away, nor, on the other hand, a niggard. His aim is to pay proportionately to service rendered. He may be crude in his methods of doing so, but that at least is his method, which is infinitely more effective than any a government uses.

5. A contractor will experiment with labor saving devices. He will invent or he will encourage inventors by his aid. What government ever bred inventors in its service? A government superintendent may occasionally be so inventive by nature that not the most discouraging situations can stifle his ambition. But, as a rule, the government superintendent, having nothing to gain by successful application of an experimental machine or process, and having much to lose in case of failure—probably his job—adheres to the ancient motto: "It is better to be safe than sorry."

6. A contractor is not restricted to working his plant in one locality nor on one class of work. Hence he is frequently able to keep his plant and his men busy, in whole or in part, nearly all the time. In the Roads and Streets Section of this book the high cost of municipal plant and supervision expenses in New Orleans illustrates the point very well. During the season when the teams can not work on paving, they are idle. So are all the "salaried men." A contractor would have kept the teams at work hauling coal, or what not, for private concerns, if not in New Orleans, then elsewhere. But the municipality of New Orleans can not engage in private work, nor can it compete for public work in other municipalities.

7. A contractor can usually buy machines, materials and supplies more cheaply than any government. The absence of red tape delays in getting "action," the certainty that no "graft" must be paid to officials, and other factors operate in a contractor's favor, to say nothing of the fact that he is usually a more skilled purchaser.

8. A contractor almost invariably does his work at less expense for "overhead charges." On the Panama Canal, which is being built by government forces, the item of General Administration alone amounts to 13 per cent (in 1909) of the total cost! And when we consider that the total cost is fully double what it would cost a contractor, we have some idea of the meaning of this expense item.

The following extracts from a few editorials of mine on this general subject of the inefficiency of the day labor system of doing

government work will be found to contain the opinions of several eminent engineers:

Thomas Telford on the Day Labor System.*—One of the greatest civil engineers of all time, and the greatest of his own time, was Thomas Telford, the inventor of the telford road, engineer of hundreds of large bridges and builder of numerous canals and docks. He was the first president (1820) of the Institution of Civil Engineers.

Of all the monuments to Telford's hard, common sense and engineering skill none is greater than the "Rules for Repairing Roads," of which he is author. Rule 7 is entitled "Management of Labour," and reads as follows:

"All labor by day's wages ought, as far as possible, to be discontinued. The surveyors should make out specifications of every kind of work that is to be performed in a given time. This should be let to contractors, and the surveyors should take care to see it completed according to the specifications before it is paid for. *Attention to this rule is most essential, as in many cases not less than two-thirds the money expended by day labor is usually wasted.*"

This rule was written a century ago, but time has not altered the nature of men nor the soundness of Telford's advice.

It is interesting in this connection to record Telford's success in the building of nearly 1,000 miles of roads in Scotland by contract. He let 120 contracts for this work, which extended over a period of 18 years, and in that time there was not a single lawsuit arising from any of these contracts. The work was done with an economy unheard of before Telford's time, and it was small wonder that his fame spread beyond the British Isles and led to his being called as consulting engineer on numerous engineering projects in Europe.

Telford had discovered—or, rather, rediscovered—the principle that workmen are far more efficient when in the employ of an individual or firm than when in the employ of a government, whether it be of county, town, city or state. His success as an engineer rested as much upon the application of this principle as upon his own genius as a designer of engineering structures.

The Opinions of Members of the Am. Soc. C. E. on the Day Labor System.†—In 1896 there appeared in the Transactions of the American Society of Civil Engineers a paper by Mr. W. W. Follett on the "Cost of Sewer Construction, Denver, Colorado," in which were given data intended to prove the economy of day labor as compared with contract work. Doubtless the author was somewhat surprised to find not a single out and out supporter of his contention among all the members of the society who discussed his paper. On the other hand, the day labor system was unanimously condemned as a system to be applied in general to city work. Some of the

*Abstract from an editorial in *Engineering-Contracting*, May 5, 1909.

†Abstract of an editorial in *Engineering-Contracting*, June 2, 1909.

expressions of opinion are not without interest even now, coming as they do from men high in the profession. We quote:

Most cities began their public works by the day labor plan, but have been forced to adopt the contract system in self defense.—Foster Crowell, M. Am. Soc. C. E.

Contract work is more desirable and cheaper as a rule than work by the day.—Henry Goldmark, M. Am. Soc. C. E.

The writer's experience has been that sewer work generally costs a city less by contract than by day labor.—William B. Landreth, M. Am. Soc. C. E.

The tabulated results [given in Mr. Follett's article] as to cost do not show any striking gain over that of contract work in this case. This is one of a few instances where experiments of this kind have been successful. In probably seven cases out of ten the political tendencies of boards made up wholly of scheming politicians to give sinecures to political hangers on would have largely increased the cost of the work.—Andrew Rosewater, M. Am. Soc. C. E.

It is the writer's opinion that in most cities public work can be done to better advantage and at less cost by contract than by hired labor.—G. T. Nelles, M. Am. Soc. C. E.

We may add that Denver sewers, under discussion, were large brick sewers, and that each brick mason averaged 2,080 brick per 8 hour day, wages being $4, which is far and away better than the usual output on day labor construction, but less than half what many contractors secure from their brick layers on sewer work.

It should also be pointed out that a strenuous effort was made by the city officials in this case to prove that day labor work would be the most economical for all sewer construction to be done in the future, and they were not only free to alter the specifications to attain their end, but naturally prompted to do so by self interest. In discussing this feature of the case, Mr. G. T. Nelles, M. Am. Soc. C. E., said:

"Another important factor in the cost of work done under proper supervision in this manner by cities is the fact that they do not enter into a binding contract with themselves to do the work in a fixed manner and under rigid specifications, as is the case when work is done by contract. On the contrary, they are always at liberty to make such change in methods or materials as experience may prove to be beneficial and economical to the work. Under the contract system it is rarely possible to make such changes, no matter how desirable they may be, without raising a cry of fraud or violating some of the terms of the contract. As a consequence whenever there is a choice of materials or methods under the contract system, *the most expensive to the contractor is usually adopted.*"

We have italicized this last clause, for, unfortunately, it expresses the truth about the tendency on the part of many engineers to exact not merely the last pound of flesh, but to call for an avoirdupois pound, although the specifications might well be interpreted to refer to a Troy pound. This particular feature of contract work is perhaps the one most worthy of careful consideration by the engineer who aims to secure low bids from reliable firms.

There is but one way of accomplishing this end—namely: by preparing specifications with as great care as is given to the work of making the drawings. Sewer specifications are, as a rule, particularly weak in all that relates to the excavation of materials. Generally no soundings or test pits are made by the engineers and no classification of materials other than "earth" and "rock" is given. Not only is there no sub-surface survey, but there is not even a fair attempt in the specifications to provide for payment based upon what may actually be encountered. Practically all the "changes" to which Mr. Nelles refers would be unnecessary were proper sub-surface surveys made in advance of making the design and drawing the specifications.

Mr. Franklin Riffle, in Trans. Am. Soc. C. E., Vol. 33 (1895), p. 590, says:

"Some years ago, while connected with railroad construction on the Pacific coast, the writer took pains to compare the cost of company work with the cost of contract work, and was somewhat surprised to discover that in nearly every case investigated the former exceeded the latter, the excess ranging from 25 to 100%. The recently constructed water works system of Portland, Oregon, furnishes an instructive example. * * * There was considerable work done by day labor, under the mistaken idea that this method would ensure the most satisfactory results, but the cost of the work largely exceeded the estimate."

The Metcalf and Eddy Report on the Day Labor System in Boston.—This report contains the results of the most exhaustive investigation into the relative economy of the day labor and the contract systems ever published and is convincing in its demonstration of the economy of the contract system. The report is one made in 1909 to the Boston Finance Commission, important extracts from which were published in *Engineering-Contracting*, Aug. 25, 1909, and in subsequent issues.

I regard this investigation as the forerunner of many more of its kind to be made by consulting engineers for finance commissions in other cities. In fact I look to see such finance commissions become permanent institutions, whose function it shall be to investigate every department of a municipality, with a view to determining *unit costs*. Thus will the public be put in possession of unbiased facts about the economic or uneconomic conduct of the business of government.

Mr. S. Whinery's Report on the Day Labor System in Boston.*—On pages 139 to 142 of his report to the Boston Finance Commission, Mr. Samuel Whinery says:

"(1) The claim that a municipality can execute its public work at an actual cost as low as the same work can be done by a contractor and thus save the profit that the contractor is entitled to make may be true as an abstract theory, but experience has shown that it is not generally true in practice. It has in many cases been

*Abstract from *Engineering-Contracting*, Dec. 29, 1909.

found true in isolated instances or for short periods of time, but when the practice has been continued for a considerable period it is almost invariably the case that direct work becomes more expensive than contract work. The reasons for this are not difficult to find. * * *

"(2) The claim that public work executed directly by the municipality is more certain to be of good quality than if done by contract is not well founded.

"It is a plausible proposition that municipal officers, having no personal financial interest in the results, will be actuated only by the desire to secure to the city the best quality of work, but experience has not shown it to be true. There are motives other than the mere saving of money that may, and as a rule do, influence city officials to cut down the cost of public work done under their direct supervision to the lowest figure, with possible detriment to the quality of the work done. * * *

"I have had good opportunity to observe in many cities the comparative quality of work done by the municipality direct and by contract, and I do not hesitate to say that, as a rule, the former is not usually superior to the latter.

"(3) The claim that it is either better or more economical for the municipality to purchase and furnish contractors the supplies required for public work is not supported by the facts, * * * many of which are obvious. Nor is it true as a rule that a better quality of supplies is secured when purchased by the city than when they are purchased by contractors under proper city specifications and subjected to proper inspection.

"(4) The claim sometimes made that by doing its work directly the municipality can so provide for the employment and control of labor as to benefit the city at large or its dependent citizens is fallacious in practice. When public work is to be done the necessary labor must be employed either by the city or by the contractor. For doing the same work the city can use no more labor than the contractor if the labor employed by each is equally efficient and equally well directed. If economical results are to be obtained, equal care and discrimination must be exercised in securing labor by the one as by the other. If it be said that the city may so manage the labor supply as to afford employment to indigent or inefficient laborers (whom no contractor would employ), who would otherwise have to be aided from the city treasury, it may be answered that the city can no more afford to employ that class of labor than the contractor, and that it is better and cheaper in the end to pension or otherwise care for the disabled or inefficient. Laborers belonging to these classes do not earn the wages paid them and a few of them scattered among strong and able workmen have a demoralizing effect upon the whole body by setting a low standard of accomplishment."

Experience With Day Labor on the Chicago Main Drainage Canal and at Panama.*—We now have the annual report of the Isthmian

*_Engineering-Contracting_, Dec. 4, 1907.

Canal Commission, teeming with arguments in favor of continuing the day labor system. We quote:

"Omitting profits derived from subsistence and general stores and assuming the hours of labor the same in both cases, it stands to reason that the government, when warranted in making the necessary outlay for plant, can do work cheaper than a contractor, for no question of profits enters into the consideration."

It does not stand to reason that any government can do work as cheaply as a private party. Indeed, to make such a claim is going contrary both to reason and to experience upon which all reasoning is founded. The Isthmian Commission goes on to explain that on jobs of less magnitude than the Panama Canal it does pay to do the work by contract because in such cases the government has neither the plant nor the organization to do the work. In the case of Panama, however, the government has both. The grave fallacy in this argument lies in the assumption that it is economic to award contracts only because a suitable plant and an organized force of men can be secured quickly. These, it is true, are factors in favor of a contractor, but if they were the only factors, government contracting would have disappeared entirely fifty years ago. The government could well afford to own a sufficient plant to do all its construction work, and it would not take long to build up an organization to handle the plant. But plant and organization are merely the tools. Back of these tools must be a great incentive if work is to be done economically with this plant and this organization. Plant is nothing, organization is nothing, unless the brain that directs both is keenly bent upon saving every penny and entirely free to bring every resource to bear in effecting economy. It is this lack of sufficient incentive and of sufficient freedom of action that makes every government manager of work far inferior to the ordinary contractor. A government employe knows that his salary will go on regardless of the cost. Earth work may be costing the government 50 cts. a yard that would cost a contractor 30 cts., but Col. Goethals will draw his salary just the same, and so will every other employe clear down to the water boy. It is true that the chief engineer is actuated by the vague desire to make a "good record," but he is also well aware that his "record" can not be measured by any standard except the accomplishment of his two predecessors. The great desire to make wealth for himself is wholly absent. His brain is warmed to mild glow by the hope of being able to "make good," but there is no fire under his boiler that sets the steam valve popping. But granting him even a considerable amount of feverish desire to "make good," we find him bound hand and foot, not by red tape but by the indifference of the vast majority of his employes. Why should his lieutenants sit up nights devising ways of reducing costs? Why should they go about jumping on the workers by day to sting them into action? The one act may break down health, they will tell you, and the other will surely make enemies of the men. What recompense will there be for these two losses? A share in the saving effected? No. A partnership in the business? No. An increase in salary? No, for

governments do not pay on the scale of what a man saves but upon the scale of what he spends. There are no bonuses, no special salaries for excellence in service, no partnerships—nothing but a mild hope that, if one does not die at the bottom, promotion to a higher rank will come some day as a result of death at the top. That is government work, and that is why a contractor's profit represents not additional cost to the government but merely a small fraction of the saving effected by a capable man driven by the fierce desire to make that saving as large as possible.

To illustrate what happens even to a contractor when this incentive is removed: On the Chicago Main Drainage Channel the firm of MacArthur Bros. was put in charge of excavating a section of glacial drift on a percentage basis. They furnished the plant and organization, but did not pay for the labor or supplies out of their own pockets. That was paid for by the Sanitary District, and MacArthur Bros. received 15% for use of plant and supervision. After a considerable amount of the earth had been excavated at a cost of 86½ cts. per cubic yard, the Sanitary District gave up this day labor method in disgust. In a report on the work Chief Engineer Isham Randolph said: "This work may be regarded as an object lesson, clearly demonstrating from an economic standpoint the unwisdom of entering into any arrangement for carrying on the construction work of the Sanitary District by the direct employment of labor." (Hill's "Chicago Main Drainage Channel," page 33.)

We cite this case because the MacArthur Bros. are among the most competent contractors in the country, but even they could not combat the irresistible tendency of men to loaf the minute they know that a government is going to foot the bill and not a contractor.

Subletting Work and Purchasing Materials.—There is seldom a contract that does not involve subcontracting, even when the original contract specially prohibits subcontracting. Every purchase of materials for which cash is not paid at once is a subcontract. The term subcontracting, however, is commonly applied to the awarding of a contract by the contractor, the subcontractor being one who undertakes to furnish the labor and materials necessary to perform a given portion of the original contract.

Whether it be a purchase of materials or an award of a subcontract, there is one thing the contractor should never neglect to do and that is to attach a copy of the original specifications to his letter or to his subcontract. In his letter or his subcontract he should make definite reference to the attached specifications, stating that the materials or the work, or both, must conform to those specifications. Failure to do this may lead to serious misunderstandings and loss. For example, in ordering paving bricks from a manufacturer if the contractor fails to say that they must be subject to the inspection and tests of the engineer and if a large percentage of the bricks are "culled" (rejected), the manufacturer may refuse to supply other bricks to replace the "culls."

Another point that should never be overlooked is to have a written contract (an exchange of letters will suffice) for any mate-

rials or work involving a sum in excess of the sum specified in the Statute of Frauds of the state in which the material is purchased. In some states this sum is less than $100 and in others it is $500. Any verbal contract, no matter how many witnesses may be brought, is voidable if the sum involved is in excess of that prescribed in the Statute of Frauds. Once the materials ordered under verbal contract have been delivered and accepted, the verbal contract as to price becomes binding.

It is poor practice, in my judgment, to buy or rent anything by word of mouth, and foremen should be required to make all purchases by written order, keeping a carbon copy. All renting of tools or plant should be recorded in writing, by an exchange of letters or otherwise, so as to have the terms of the rental signed by both parties. I have had the verbal rental of a plow by a foreman cost me $100 in lawyers' fees, etc.

A few suggestions regarding the subletting of work: Subletting should not be forbidden in the original contract. Repeated subletting of the same part of a job may be, and often is, pernicious in its effect upon the quality of the work. One subletting often results in lower cost of work, for a subcontractor who gives all his attention to a small job can usually get the workmen to do more work than a large contractor who has many things to attend to. The subcontractor is really a superintendent or foreman whose salary is paid in profits, and he has the best possible spur to secure the greatest possible economy.

The letting of several independent contracts for the different parts of a structure often leads to delays and claims for extras due to delays. One independent contractor may purposely delay another. All this is avoided by awarding the whole structure to one contractor, who can usually manage several subcontractors much better than several independent contractors can be managed by an engineer.

On the other hand, it is not an uncommon mistake to let a contract too great in size to secure active competition from several contracting firms. One of the best managed large pieces of public work was the Chicago Main Drainage Canal, contracts for which were let in sections of moderate size; with the result that there were many able competitors who named low prices.

Instructions to Superintendents and Foremen.—Some of the most successful contracting firms have sets of rules and instructions printed for the use of foremen and others. Certain of the "rules" are inflexible and must be obeyed; others are more in the nature of suggestions intended to guide the foreman in doing his work, handling his men, purchasing materials, and the like.

Gilbreth's "Field System" is a book of rules used by him in managing his contract work. His "Bricklaying System" is another such book.

I will give a list of instructions that is by no means exhaustive, but varied enough to give some hints as to the character of a set of instructions. Rules such as these can be mimeographed on

small sheets of paper and bound together with clips, so that they can be carried in the pocket for reference.

1. When a foreman arrives at a place where he is to have charge of work, he must notify the home office at once by postal card, giving the address of his boarding place and his office address.

2. A daily report must be sent to the home office on the blanks provided. If no work is being done, still a report must be sent in stating that fact and giving reasons for delays, etc.

3. Each foreman must keep a small diary in which to jot down the principal events of the day. Such a diary may be of great value in case of a law suit.

4. Each foreman must write all orders for materials, supplies, etc., in the book provided for the purpose, so that a carbon copy of every order will be kept. He must be careful to insert the day of the month. When a foreman wishes grading stakes or instructions from engineers in charge of work, let him send a written order to the engineer stating exactly what is wanted. This precaution may save misunderstandings and delays, and the carbon copy of such an order is often useful to check the memory. The sooner a foreman learns to be methodical in such small matters, the sooner will he be fitted to handle larger matters.

5. No superintendent, walking boss, engineer, time keeper, or other employe of this firm is permitted to give an order direct to any workman, except in case of great emergency. Not even a member of this firm is exempt from this rule. The foreman in direct charge of a gang of men is the only man permitted to instruct his men what to do. He is the officer in charge, and his superior officers must not intentionally or unintentionally degrade him in the eyes of his men by issuing orders over his head.

6. A foreman is not permitted to work with his men. He is employed to use his wits, not his hands. Occasionally he must instruct a man how to do his work, but he must teach the man and not attempt to take the man's place. It may take a foreman longer to teach a man than to do it himself; nevertheless it is cheaper in the long run to teach the man.

7. Do not use laborers to do the work of masons or carpenters, but provide a sufficient number of laborers to assist the skilled workmen. A 15-ct. man can lift as many pounds of wood or stone as a 50-ct. man. Exercise your wits in keeping each class of men busy at their particular class of work.

8. In rainy weather keep all steady pay men busy overhauling machines and tools, sharpening tools, branding tools, splicing ropes, etc.

9. Rush all percentage or force account work exactly as if it were part of the regular contract. The reputation of this firm is worth more money than can ever be made by "making work last."

10. Small jobs of extra work are usually taken on a basis of 20% profit on both materials and labor. This leaves but a small margin of profit after deducting general expenses. It is particularly desirable to work as many men as possible on a small job, so as to reduce the percentage of general expenses.

11. Keep the addresses of good workmen.

12. Do not be a "good fellow" with the men under you after working hours, or you will lose their respect. Remember the old adage, "Familiarity breeds contempt."

13. In case of any accident to a workman or to a spectator notify the home office at once by letter. If the accident is fatal, notify by telegraph or telephone. We are insured against such accidents, but by the terms of our policy we must notify the insurance company within 24 hours.

14. The best and cheapest insurance against accidents is care. Provide barricades, warning notices and red lights wherever an excavation is made. Even a small hole unprotected may cause the loss of a life, for which the courts may hold this firm responsible. When a street is closed by barricades, do not permit an outsider to enter even at his own risk, for should an accident occur a law suit is certain to follow regardless of the rights involved.

15. Accept no orders for extra work except in writing, and forward such orders at once to the home office.

16. Fill in your expense account blank every Saturday night and send to the home office.

17. When plans are received indorse your name upon them, with the day of the month and year. Write on blueprints with a red pencil.

18. Avoid all controversy with an engineer or inspector. A small quarrel often leads to a big loss. Notify the home office in case of unfair or unreasonable orders.

19. When a car arrives, record its number and character of contents. Remember that a demurrage is charged on all car freight held more than 72 hours; but on most roads demurarge is estimated by averaging. Thus, if one car is held 24 hours before unloading and another is held 96 hours, the average is $(24+96) \div 2$, or 60 hours.

20. Pile lumber with the boards slanting so that water will drain off. Lay as few boards or timbers directly on the ground as possible. See that the top layer of boards is turned over occasionally to prevent warping.

21. Insure all lumber and timber work against fire.

22. Count and measure all sticks of lumber to check the bill. To calculate the number of feet board measure (ft. B. M.) in a sawed stick of timber, multiply the width in inches by the thickness in inches, divide this product by 12, and multiply the quotient by the length of the stick in feet.

23. See that all shipments of materials are counted or measured and recorded.

24. For convenience in estimating the weight of materials remember the following:

Material.	Cu. ft. per ton of 2,000 lbs.
Water (62½ lbs. per cu. ft.)	32
Sand or gravel	20
Broken sandstone, limestone or granite	22
Broken trap-rock	20
Solid blocks of granite	12
Coal, broken	40

Green white oak is heavier than water and weighs more than 5 lbs. per ft. B. M. (there being 12 ft. B. M. per cu ft.). Green southern yellow pine weighs 4½ lbs. per ft. B. M. Kiln dried oak weighs 3¾ lbs. per ft. B. M. and kiln dried yellow pine weighs 3 lbs. per ft. B. M. In any case, by floating a block of wood in water and measuring the total depth of the block and the submerged depth, the weight can be calculated by simple proportion, thus:

Depth of block submerged: Total depth of block:: The weight per ft. B. M.: 5.2. Thus if the block is 6 ins. deep and 4 ins. are submerged when it floats, we have:

4 :6 : :x :5.2.

Whence we find that x is nearly 3½ lbs. per ft. B. M.

Familiarize yourself with other rules useful in computing weights, etc.

25. On short hauls where dump wagons are not available provide extra wagons which can be loaded while the full wagons are going to the dump and returning. Extra wagons can usually be rented, and in some cases it will pay to buy them, for the lost team time soon eats up the price of a wagon. Extra wagons are especially useful where a small gang of men is unloading brick, stone or timber from a car onto the wagon. When a team comes up with an empty wagon, unhitch from the empty, hitch to the full wagon, and with a tail rope pull the empty wagon up to place as the full wagon moves ahead.

26. In erecting a derrick or pile driver remember that a gin pole or mast can often be used to advantage. Gin poles are not used as often as they should be for this kind of work.

27. In erecting a trestle for falsework, frame and bolt the bents together on the ground, then up-end them.

28. Use round timber for legs of temporary trestles, for trench braces, and wherever struts are needed. Round timber can usually be bought for much less money than sawed stuff.

29. In buying brick consider the size of each brick; bricks vary greatly in size. Large bricks are worth more per M than small ones. If 2x4x8-in. bricks are worth $6.50 per M, every ⅛ in. increase in the length adds 10 cts. per M to the value, and every increase of ⅛ in. in thickness adds 25 cts. per M.

30. In buying cement, consider the size of the barrel and the amount of cement paste that can be made with a barrel. There is a great variation in the product of different factories.

31. Buy cement in wooden barrels for use on small jobs that are liable to lag. Buy cement in cloth bags for most work. Pack the bags in bundles of 50, and ship to factory. Cement improves with age up to a certain point, if the air is not too damp. Use the oldest cement first.

32. Dynamite must never be thawed in any way except with a hot water thawer of the kind furnished by this firm. Never thaw in front of a fire, or on a hot stone removed from a fire, or by piling sticks on a boiler, or in an oven. We know of fatal accidents due to each of these methods. There may be safe methods

other than the one above ordered, but we can not afford to experiment where lives are at stake.

33. Never store dynamite, or acid, or gasoline in a tool box. The dynamite may be exploded; the acid vapors will eat into ropes and rot them; the gasoline vapors may explode or spilled gasoline may result in a fire. Use sand to put out a gasoline fire. Hemp rope is weakened not only by acid vapors, but by saturation with oil. All rope should be kept dry.

34. In using steam engines, steam drills and derricks, the following precautions should be observed:

Daub grease over all bright parts before storing, also in wet weather. Oil the derricks, crushers, wire ropes, and all movable parts of machines every day. Cheap black grease is usually daubed on wire ropes; but where the ropes are moving over sheaves almost continuously, provide an oil drip cup to feed oil, drop by drop, onto the moving rope.

Do not permit men to wash their hands in the water barrel or tank that supplies water to a steam boiler, for the grease from their hands will cause "priming."

Boiler flues are frequently "burned" because water is allowed to get too low in the boiler. Aside from the danger of a boiler explosion in such cases, there is the certain cost of repairs. See that the steam cocks are blown off several times daily, and do not rely upon the water glass.

A lazy or ignorant fireman will pile on coal and then rest until it has burned low. See to it that a thin bed of fuel is kept steadily burning. On large boilers use an automatic pressure recording gage to make the firemen attend to their business properly. It will not only save coal, but result in greater output of engines and steam drills.

Cylinders of engines and steam drills are frequently cracked in cold weather by suddenly letting in steam. To avoid this open drip cocks and cocks on steam chest and blow in steam for a few minutes to warm up the cylinder before starting the machine. A broken cylinder may delay work for a week.

Do not let a friction clutch get wet, for it may slip if it does.

Lower the boom of each derrick at night, so that it can not be dropped by some one for fun or for spite. Lay down short logs at intervals to keep the hoisting rope clear of the ground.

The foregoing will serve as examples of instructions and hints issued by a contractor. As they stand they possess the disadvantage of not being classified into instructions that *must* be obeyed and hints that *may* be followed.

Each contracting firm will have certain classes of work in which it specializes, and will find it advisable to prepare mimeographed or printed instructions not only of a general nature but of a special nature. Thus a firm engaged in building construction may give sketches of scaffolding and instructions as to its erection. A firm engaged in bridge building may prepare a set of rules to guide the foremen in coffer damming and in false work building.

System is fast taking the place of the hit or miss style of direct-

ing work. A well prepared set of instructions to foremen is an essential part of any complete system of management.

The Ten Laws of Management.*—The managing of industrial enterprises, such as construction work in the field, is still an art, and there are few who realize that it can be reduced to a truly scientific basis. Nevertheless there are certain underlying principles of effective management of men which may be expressed in the form of laws. Application of these laws leads invariably to a greater output on the part of workmen, and this invariability of result proves the scientific basis of the laws. The most important of them can be grouped under ten general headings, which are as follows:

1. The law of subdivision of duties.
2. The law of educational supervision.
3. The law of coordination.
4. The law of standard performance based on motion timing.
5. The law of divorce of planning from performance.
6. The law of regular unit cost reports.
7. The law of reward increasing with increased performance.
8. The law of prompt reward.
9. The law of competition.
10. The law of managerial dignity.

Below are given the main characteristics of each:

1. The Law of Sub-Division of Duties.—Men are gifted with faculties and muscles that differ extremely. One man will excel at running a rock drill, another is better at lifting loads, a third is clever in the application of arithmetic, a fourth is a born teacher—and so through the gamut of human occupation. Moreover, practice serves to accentuate these inborn differences. It is clear, therefore, that the fewer duties any one man has to perform, the easier it is to find men who can do the task well. But give a man many duties to perform and he is almost certain to do at least one of them poorly, if, indeed, all are not miserably attended to. Hence the following law of management: *So organize the work as to give each man a minimum number of duties to perform.*

This law needs little emphasizing as to its general truth, but it is nevertheless ignored frequently by those who have not applied a scientific treatment to management. Thus a foreman is often charged with a multitude of duties. He is expected, for example, to watch the workmen and spur them to action when slothful, to teach his men how to do their work in a more economic fashion, to discover and remedy defects in the machines and tools employed, to plan the arrival of materials at the proper time and in the proper amount, to keep records of daily performance, etc., etc.

Mr. Fred W. Taylor was the first, we believe, to urge the subdivision of the duties of foremen and to have what he calls "functional foremen." One foreman, for example, is the machinery and tool foreman. It is his sole duty to study the work done by machines and tools, to effect improvements, to reduce delays, and to supervise repairs.

*These ten laws of management were first published in "Cost Keeping and Management Engineering," by Gillette and Dana.

Another foreman is the gang foreman. His function is to organize the gangs, to direct their operation, and to instruct them in the performance of their work.

A material foreman is employed on large jobs. His function is to confer with other foremen and ascertain what materials, machines and supplies will be needed. He orders the materials, arranges for their shipment, and follows up the manufacturing and railway companies to secure prompt delivery. If necessary, he sends men to the factory, to the stone quarry, or to the freight yard to see to it that deliveries are made with dispatch. Such a man is often invaluable, for upon him may depend the entire progress of the work.

According to the magnitude of the contract there may be different kinds of foremen, all coming in contact with the same men perhaps, but all performing different functions. Such an organization as this differs radically from a military organization, wherein each man reports to only one superior officer on all matters.

Most industrial organizations today resemble military organizations, with their generals and intermediate officers, down to corporals, each man reporting to but one man higher in rank. There is little doubt that the present tendency in industrial organizations is to abandon the military system to a very large extent, and for the following reasons:

A soldier has certain duties to perform, few in number and simple in kind. Hence the man directly in command can control the actions of his subordinates easily and effectively. Control moreover should come invariably from the same officer, to avoid any possibility of disastrous confusion and to insure the instant action of a body of men as one single mass. On the other hand, industrial operations do not possess the same simplicity, particularly where men are using machines, nor is there the necessity of action in mass. The military organization, therefore, should be modified to suit the conditions; and one of these modifications is the introduction of two or more foremen in charge of certain functions or duties of the same men or groups of men.

On contract work it is often impossible to subdivide the duties of men to as great an extent as can be done in large manufacturing establishments. The smaller the contract, the less the subdivision of duties possible. *In such cases an approach to the ideal system of subdivision is secured not by employing different men for different purposes but by a systematic assignment of duties to the same men to be performed at specified hours of the day or days of the week.* Thus a small gang of carpenters is engaged in building forms for concrete, in repairing wooden dump cars, and in framing and erecting trestle work. By timing the men and by planning their work upon the timing records and the requirements of the work this carpenter gang can be assigned certain hours or days for each class of work. Thus is avoided the intermittent and uncertain shifting of the gang from one class of work to another, involving not only a loss of time in frequent shifting but a loss of interest in work that is done piecemeal. Moreover a methodical

change of occupation permits a methodical record of the number of units of each class of work performed, and thus leads to the use of the bonus system of payment.

2. The Law of Educational Supervision.—It is not alone sufficient to give instructions to workmen and foremen from time to time by word of mouth, but the gist of all important instructions should be reduced to written or printed form. Among contractors the pioneer observer of this law is Mr. Frank B. Gilbreth, whose "Field System" is a 200-page book of rules for his superintendents, foremen and others to follow. His "Bricklaying System" is another set of rules for the guidance of his brick masons and foremen.

Among manufacturers there are many examples of those who have prepared more or less elaborate sets of rules to be followed, but the most interesting of these compilations that have come to our attention is the one furnished to its salesmen by the National Cash Register Co. In this book are gathered a vast number of useful hints and practical suggestions and arguments to be used in selling National cash registers. Each possible objection that a prospective purchaser may raise is met with one or more specific answers. This company not only provides its salesmen with a text book but has a school for training salesmen. At regular intervals all the salesmen meet together and discuss their respective methods of selling cash registers. Any new suggestions that are good become subsequently a part of the book of instructions. Thus the combined wisdom of hundreds of salesmen is preserved and delivered to every salesman that the company employs. This plan is followed also by many of the life insurance companies. Railway companies have long made it their practice to furnish their civil engineers with printed sets of rules for railway location, as exemplified in McHenry's "Railway Location." All these are forms of educational supervision, and some are very elaborate. The small contractor need not necessarily have a printed book of rules of his own making, but he can supplement some such book of rules and hints by a typewritten or mimeographed set of sheets containing the most important of his own instructions. In this manner the repetition of a costly blunder by a foreman or workman can be avoided by a special rule or hint, while a labor saving "trick" can be passed on to other men in the contractor's employ.

In developing a system of educational supervision the greatest assistance can be obtained from articles in engineering and contracting periodicals, for there will be frequently recorded labor saving methods well worthy of trial by other contractors. In a long article it may be only a small hint that is worthy of being abstracted and placed among the hints for foremen.

In preparing a set of rules and hints, take pains to distinguish sharply between what is a rule always to be followed and what is a hint to be followed optionally. It is well to have a set of *rules*, each with its specific number, and a separate set of *hints*, also numbered.

The second law of management is briefly this:

Secure uniformity of procedure on the part of employes by providing written or printed rules, supplemented by educational suggestions or hints to guide them in their work.

3. **The Law of Co-ordination.**— *So schedule the performance of each gang of men that they will work in perfect coordination with other gangs, either adjacent or remote.*

Perfect coordination involves the working of each man to his capacity all the time. This necessitates not only the organization of gangs of just the right size but the prompt arrival of standard supplies and materials, and freedom from breakdowns of plant.

An examination of almost any piece of construction work in progress will disclose the fact that most of the men spend a considerable portion of their time waiting either for somebody else to do something or for materials to arrive, before they can proceed. The cause is improper coordination of the work. One gang may have too many men and therefore may be able to work considerably faster than another, and be continually catching up with it. They will then adopt a slower pace, keep seemingly busy, and manage to kill a large percentage of their working time. These delays are chargeable to lack of coordination, although a careless inspection of the work may seem to indicate that everything is going smoothly. A job can look smooth and at the same time be so badly coordinated as to be uneconomical.

The necessary adjuncts to proper coordination of work are briefly as follows:

1. A carefully drawn schedule of performance.
2. Regular arrival of material and supplies.
3. Prompt and proper repairs to equipment.
4. The proper quality of supplies.

The best method that has so far been devised for making things happen on time is first to prepare a time table, and then to live up to it as far as the interruptions of the weather and the limitations of human nature will permit. To prepare a time table properly it is necessary to know how fast work can be done under the conditions which are to govern it. At the best there will be a considerable variation to be accounted for by ignorance on the part of the planning department on the one hand and by the interference of the elements on the other. A form of chart, made on tracing cloth, with various symbols to indicate the kinds of work to be done, has been found very useful. As the work progresses the performance can be checked off on the chart, and thus indicate whether the work is proceeding on time. Where the work is such as that of building construction and there is but little storage capacity for materials, it is best to have the chart prepared a considerable time in advance so that materials will arrive when they are needed and yet not so much in advance of the proper time as to require large storage capacity at the site of the work.

4. **The Law of Standard Performance Based on Motion Timing.** —Nearly every operation performed by a workman involves several

motions, although at first sight it may often seem that there is but one.

Mr. Frank B. Gilbreth has coined the term "motion study" to denote his method of observing the number and kind of motions made by a man—a brick layer, for example—in performing a given operation. His plan is to analyze the motions, assigning a name to each motion. His next step is to endeavor so to arrange the supply of materials, the position of tools, etc., as to reduce the number of motions and the distance of each motion to a minimum.

TABLE VII.

Cableway No. 2, Handling Concrete.

Process	1908. Observations.	Min. time.	Ave. time.	Max. time.	Efficiency. Standard time.	Per cent.
Rl 40 ft.	30	6.0	10.5	17.3	6.0	40.0
Tl 470 ft.	33	31.0	47.3	63.0	31.0	65.5
Fl 123 ft.	37	22.0	30.8	44.7	22.0	71.5
——— D.	37	16.8	61.7	140.4	16.8	27.2
Re 123 ft.	36	19.4	23.7	29.3	19.0	80.4
Te 470 ft.	36	26.5	37.2	64.5	26.5	71.1
Fe 40 ft.	35	11.0	42.9	96.0	11.0	25.6
———L	28	12.0	73.2	234.0	9.4	12.8
Totals, 1,266 ft.		144.7	327.3	689.2	141.7	

TABLE VIII.

Cableway No. 3, Handling Concrete.

Process	1908. Observations.	Min. time.	Ave. time.	Max. time.	Efficiency. Standard time.	Per cent.
Rl 40 ft.	18	8.0	13.6	18.2	6.0	44.1
Tl 470 ft.	17	35.5	39.3	68.0	31.0	78.0
Fl 123 ft.	21	25.0	39.4	77.0	22.0	55.9
———D	22	20.0	62.5	119.0	16.8	26.9
Re 123 ft.	22	19.0	28.5	36.0	19.0	66.8
Te 470 ft.	22	30.0	46.6	102.0	26.5	56.9
Fe 40 ft.	20	18.0	29.1	48.0	11.0	37.8
———L	16	38.0	75.6	220.0	9.4	12.4
		193.5	334.6	688.2	141.7	

Mr. Fred W. Taylor was the first, we believe, to adopt the practice of invariably studying each motion by the aid of a stop-watch. A large number of stop-watch observations not only give the average time of a motion, but, what is of far greater importance, they indicate what the minimum time for each motion may reasonably be expected to be. It then follows that the sum of these minimum times for the different motions represents a standard time of accomplishment of the entire process. Hence our law of motion timing:

In the performance of every process the sum of the minimum times observed for each motion gives a standard of performance possible of attainment under sufficient incentive.

Mr. Harrington Emerson calls this standard of excellence 100%, and has developed the plan of rating all actual performances in percentages. Thus if the standard time for drilling a 10-ft. hole in a certain rock were 60 minutes and, if the actual time were 90 minutes, this performance would be rated at 60÷90=66.67%.

In establishing a standard time of performance, the first step is to ascertain the unit times upon the work as ordinarily performed. The next step is by study of the time elements and the local conditions to eliminate as many motions as possible and to reduce the time of others, either by shortening the path of motion or by accelerating the velocity of the motion.

To illustrate by an example we give the following time study, which was made by Mr. Dana some time ago on some cableway work. Since this was done the Lidgerwood Mfg. Co. has completely redesigned its cableway engine and fall rope carriers and has introduced new features in control (notably in the Gatun cableways in Panama). Therefore, while the data are correct as history, they must not be taken as indicating the limit of present possibility. A considerable number of studies was made, but one only is given for purposes of illustration. (See Table VII, p. 70.)

The first column gives the abbreviations of the processes, distances, etc.; the second gives the number of recorded observations on each process; the third gives the minimum observed time in seconds for each process in that table; the fourth gives the average; the fifth gives the maximum time; the sixth gives the minimum of all the observed times for each process. While this is by no means the shortest possible time in which the process could be accomplished, it is the shortest one observed, and has here been taken to represent standard (100%) efficiency. By dividing the standard time by the average for each process the average efficiency as observed is obtained. This is shown in the seventh column.

As a result of this time study, it was possible to make an estimate of the probable increase in efficiency that could be obtained by rebalancing the engines. A further improvement was discovered in the method used in signaling to the operator, and an estimate of the saving to be obtained in this manner was made. A further improvement in regard to the position of the operator was discovered. A collateral improvement was perceived in the line of altering the design of the towers, so that the cost per unit of handling materials could be reduced, and further suggestions of a confidential nature, which we are not at liberty to discuss here, were made.

5. The Law of Divorce of Planning From Performance.—As a corollary to the law of the subdivision of duties, we have the law of divorce of planning from performance, first formulated by Mr. Taylor.

According to the old style method of management, each foreman is left largely to his own resources in planning methods, in addition to his other functions. This multiplicity of duties can be properly performed only by a foreman possessed of a multiplicity of talents. Since few men can comply with such a specification for brains, it follows that good foremen of the old style are rare indeed. The modern system of management consists, as far as possible, in taking away from the foremen the function of planning the work, and

in providing a department to do the planning. Under planning we include inventing, that is, the improvement of existing methods and machines.

A common error in management is the assumption that the man on the job in direct charge of the work is the man best fitted to plan and improve. Nothing is further from the truth. Rare, indeed, is the man possessed of a trained inventive faculty, and it requires such a faculty not only to develop new methods and machines but to plan the use of any machine with greatest economy. Nearly every piece of contract work presents new conditions, and this solving of new economic problems is beyond the power of any but the trained and skilled economist. But even where the problems remain identical, the necessity of a divorce of planning from performance exists, as we shall indicate.

The brain is an organ that requires frequent exercise in doing the same thing before it becomes proficient enough not to suffer great fatigue. Thus, the man who is learning to ride a bicycle finds that half an hour's lesson has tired him more than ten hours' work at his accustomed occupation. Attempting to do something new is wearisome beyond measure, except to the mind whose training has been in solving new problems. Hence the ordinary man finds much fatigue and little pleasure in attempting to do his work in a fashion that differs at all from that to which he has long been accustomed. The mental inertia that resists a change in methods of performing work is almost beyond comprehension, and it is found not only in the lowest type of workman but in the highest.

Repetition develops skill, and skill gives pleasure. To a strong man used to his work there is actual pleasure in mowing hay, as Tolstoi has admirably pictured in one of his novels. Conversely, fatigue merges into pain and is repulsive.

In addition to these fundamental reasons why men adhere to precedent in their performance, there is the fear of ridicule in case of failure to succeed in any new attempt. The child learns to speak a foreign language more rapidly than an adult not only because of a more "flexible tongue" but because it does not fear laughter at its blunders. Partial failure is expected of the child, and it is not ridiculed. But an adult seems witless if he does not immediately learn the new word and its pronunciation; hence the laughter. So it is with every new performance. Furthermore, a serious mistake may lead to the loss of a position, thus adding another reason for sticking to the "good old way."

Finally, there is no method so fruitful in effecting improvements in methods and machines as a study of the time required to perform each movement or operation. A workman or foreman rarely studies his own work in this manner. Hence his experience, upon which he is wont to brag, is like the experience of the swallow building its nest—an unchanging adherence to precedent, regardless of possibilities of improvement.

It is a significant fact that nearly all the great inventions have been the product of brains divorced from the actual performance

of the machines that they have invented. Eli Whitney, inventor of the cotton gin, was a lawyer, and not even a southern planter. Smiles' "Self Help" is a volume full of instances of important inventions made by men remotely, if at all, connected with the class of industry in which their machines are used. Nothing, therefore, is more ridiculously illogical than the common belief that the "men behind the gun" are either capable of being the inventors of the gun or the ones most likely to improve it. Yet it is this illogical belief that prevents railway companies, manufacturers and contractors from making hundreds of radical economic improvements.

Summing up, we have this law:

For maximum economy of performance, the planning of methods of doing work should be the sole function of a manager who is not a workman himself nor in direct charge of the workmen.

6. **The Law of Regular Unit Cost Reports.**—Having planned a method of performance, it becomes necessary to secure daily, weekly and monthly reports of such completeness that a manager can tell, almost at a glance, what the actual and relative performances are. This systematic reporting is more fully treated under the head of cost keeping. The success of nearly all large corporations, such as the Standard Oil Company, is due, in large measure, to a system of regular reports that put the various managers in constant touch with the performance of the men under them. Reports to be of much value must come at short, regular intervals, must be in the same form, and must show quantitative results that admit of instant comparison with previous reports. To permit comparison there must be either similarity of conditions, or there must be a reduction to units that are themselves practically identical. For example, a weekly record of the number of yards of earth excavated and hauled at a given unit cost is usually of little or no value to the manager unless there is a further subdivision of units of cost. The cost of loading per cubic yard should be segregated from the cost of hauling, so that the cost of hauling can itself be expressed in the unit of the yard-mile or ton-mile hauled.

The law of regular unit cost reports may be formulated as follows: *Report all costs in terms of units of such character that comparison becomes possible even under changing conditions, and let these reports be made daily if possible, weekly in any event, and with a monthly summary.*

It is in the adherence to the terms of this law that managers of contract work in the field will find their greatest difficulty. First, there is the difficulty of selecting suitable units upon which to report costs. In pavement work, the square yard is a convenient unit and the number of units is easily measured daily. But in reinforced concrete building construction, there is needed not merely the cubic foot or cubic yard unit, but many others, some of which are not easily ascertained every day.

For example, the pound of steel reinforcement is one unit upon which reports should be made, for the number of pounds of steel per cubic yard of concrete differs widely. The thousand feet board

measure in the forms is another necessary unit, and the square foot of concrete area covered by the forms is still another. Yet these and other units must be used to admit of any rational comparison of performance from day to day and week to week.

Furthermore, such units must be properly selected for the still more important purpose of paying the workmen according to any bonus system. In another chapter we discuss this problem of selecting units of measurement at considerable length, for upon such selection depends the success of contract work under the modern method of management.

7. The Law of Reward Increasing With Increased Performance. —*All payments for work should be proportionate to the work done.* This is the fundamental law of economic production. When this law is ignored—and it is partly ignored to-day on practically every class of work—the producer ceases to take keen interest in his work. Under the common wage system of payment, one brick mason receives as much as another, regardless of skill and energy. Individual incentive is lacking, save as it is supplied by fear of discharge. When laborers, working under the wage system, are put at the task of shoveling earth into a wagon, each man seeks to do as little as his neighbor, and the slowest becomes the pacemaker for the rest. Such ambition as any individual may possess is stifled by the knowledge that his increased output will never be known by his employer, and consequently never rewarded. Moreover, an ambitious man in such a gang is chided by his fellows who warn him not to set a "bad example" by working himself out of a job.

The wage system is responsible in the first place for lack of sufficient incentive to good performance, but its vicious effects have been greatly augmented by the stupid actions of many labor unions, such as the restriction of daily output, the limiting of the number of apprentices, the demanding of wages that have no relation whatever to the output of individuals, the refusal to work under foremen who are not also members of the union, the refusal to do any sort of work except that prescribed by the union, and the like. In the long run, all such restriction of output, whether due to the lack of sufficient incentive, or to the rules of labor unions, or to the customs of a country crystallized into caste such as exists in India, lead to a reward commensurate with the output. Summing up: The wage received becomes ultimately proportionate to the output. The high wages prevalent in America are due neither to labor unions, as some profess to suppose, nor to abundance of natural resources, but to the fact that in America labor unions have not thus far greatly restricted the output of individuals except in a few trades, and more particularly to the fact that they have not opposed the introduction of labor saving machinery. In addition, American managers are far in advance of all others in their recognition of the fundamental law of management—namely, that the reward should be proportionate to the performance. Hampered though they have been by the wage system, American managers have been liberal in their policy of payments for work performed. In recognition of his share in the greater output of earth excavation, the steam

shovel enginemen in the United States receives $125.00 to $175.00 a month.

Within the past decade still further strides have been made by American managers toward a more effective recognition of this fundamental law of proportionate rewards. Various systems of payment, known as the bonus system, the differential piece rate system, and the like, have come into more general use, and even the old piece rate system has received a new lease of life, all tending wonderfully to stimulate the energy and wits of workmen, because they are in accord with the law of proportionate reward.

8. **The Law of Prompt Reward.**—Any reward or punishment is that is remote in the time of its application has a relatively faint influence in determining the average man's conduct. To be most effective, the reward or punishment must follow swiftly upon the act. Hence a managerial policy that may be otherwise good is likely to fail if there is not a prompt reward for excellence. Most profit-sharing systems have failed, principally because of failure to recognize the necessity of prompt reward, as well as because of failure to recognize the necessity of individual incentive.

The lower the scale of intelligence, the more prompt should be the reward. A common laborer should receive at least a statement of what he has earned every day. If, in the morning, he receives a card stating that he earned $2.10 the previous day, he will go at his task with a vim, hoping to do better. But if he does not know what he has earned until the end of a week, his imagination is not apt to be vivid enough to spur him to do his best.

A daily or weekly statement of earnings, followed by prompt payment, is a stimulus essential in securing the maximum output of workmen.

9. **The Law of Competition.**—The pleasure of a competitive game lies in conquering an opponent, and this follows logically from the fact that competitive games are an evolution from the primitive chase or battle. Work conducted as a competition becomes a game, and thus stimulates those engaged not only to strive with great energy but to derive keen pleasure from the contest. The business man who continues to pile up millions, long after his wealth is sufficient to satisfy every possible want, does so from pure joy in the contest to excel others engaged in the same business. He is following the law of competitive work.

By pitting one gang of workmen against another gang, the spirit of contest is easily aroused. But it is impossible to maintain this spirit indefinitely without following the seventh law of management of men—namely, by making the reward proportionate to the performance. When, however, this seventh law of management is observed, an added spirit is given to men by pitting one gang against another. Thus, in laying concrete by hand for a pavement, the best method is to have two distinct gangs working side by side, each gang concreting from the center of the street to the curb. When this is done under a bonus system of payment, the output is astonishing

Where competing workmen cannot see one another's output, a bul-

letin board should be used, whereon the number of units of work performed by each man or each gang of men should be posted.

Convert work into a competitive game by organizing competing gangs of men and by posting their performance.

10. The Law of Managerial Dignity.—That there should be anything like caste among managers seems, at first, repulsive to democratic principles of government, whether the government be political or industrial. Nevertheless, a study of the personality of the most successful managers usually discloses a characteristic of firmness coupled with a sort of austere dignity. The best manager is never "one of the boys."

Managerial control reaches its acme of excellence in the army, and there we find class distinctions most scrupulously observed. The officers do not "mess" with the men, nor do they form close friendships with the soldiers in the ranks.

Familiarity breeds contempt, or it breeds at least a feeling that the great man is not so great after all. All managers are under the constant fire of criticism of their subordinates, whether they realize it or not. The best shield that a manager can wear is distance. His little foibles—and all men have them—may thus be kept concealed. It is essential that they be concealed, for men of less mental endowment, will always seize upon the little defects of greater men's character or attainment as evidence of lack of any real superiority. The eye of criticism is a microscope for human frailties. Being a microscope, it is wise to keep beyond its range, so that the whole character may be viewed by the naked eye in its true perspective.

Discipline in an industrial army is as essential as in a military organization, and it is best secured by military methods. This involves: (1) The social separation of the officers from the men; and (2) a sequence of responsibility from the man in the ranks to the highest officer.

For every act on the work every man should be responsible to some particular man higher in authority. There should never be any doubt as to whom a man is responsible; but it does not follow that a man should be responsible to only one person, except for certain acts. As we have previously shown, an industrial organization may have several *classes* of foremen, to each of whom each workman is responsible for certain acts. What we now emphasize is the importance of not dividing the responsibility for any particular act. A contractor, for example, should rarely give any orders to a workman. All orders should come through the proper foreman. To do otherwise results not only in reducing the workman's respect for the foreman, but it frequently angers the foreman, who feels that he has lost dignity in the eyes of the workmen.

It is often wise to change foremen from one gang to another, in order to preserve the class distinction between foremen and men. As foremen become acquainted with the men, they generally want to be regarded as good fellows, and will then permit infractions of rules and a general decrease in activity. Who has not noticed that

short jobs usually move with a "snap" that is not always characteristic of longer jobs?

We may sum up thus:

Discipline is best secured by managerial dignity, and dignity is best preserved by social separation of managers from subordinates and by an invariable sequence of responsibility.

Measuring the Output of Workmen.*—Before men can be paid according to their performance it obviously is necessary to devise methods of measuring the number of units of work done, but it is not always so obvious what units to select nor how to measure them readily after the selection of units has been made. Indeed, this difficulty accounts in large part for the slowness with which piece rate and bonus systems have been adopted.

Subdivision of Units into Other Units. In engineering construction the cubic yard is a very common unit upon which contract prices are based, but the cubic yard itself is frequently a very uncertain unit of performance, for it is a composite of other units. Thus, in rock excavation there are several distinct operations involved, which may be enumerated as follows:

1. Drilling.
2. Charging and firing (or blasting).
3. Breaking large chunks to suitable sizes.
4. Loading into cars, carts, skips, or the like.
5. Transporting.
6. Dumping.

The important item of drilling depends largely upon the spacing of the drill holes, which varies in different kinds of rock, and in different kinds of excavation, trenches and tunnels requiring close spacing. Clearly, then, the lineal foot of drill hole is a unit of work that must be adopted by the rock contractor in measuring the output of his drillers, and not the cubic yard.

Transportation is largely a function of distance, hence the unit of transportation cost should be the ton (or yard) carried 100 ft. or 1 mile, and not the cubic yard without the factor of distance.

Our first rule to be applied in seeking units that truly express the amount of work done is as follows: *Divide the contract price units into sub-units, selecting the "foot-pound" of work as the sub-unit wherever possible.*

A foot-pound is the unit of work used in theoretical and applied mechanics. It is the amount of work required to lift 1 pound a height of 1 foot. All forms of work are capable theoretically of being expressed in foot-pounds, but it is often very difficult to do so in practice. For example, it is not an easy matter to ascertain how many foot-pounds of work a man performs in shoveling earth into a wagon, for there is not only the number of foot-pounds involved in lifting the earth but in pushing the shovel into the earth,

*The following pages relating to the measurement of the output of workmen have been abstracted from "Cost Keeping and Management Engineering," by Gillette and Dana.

in lifting the shovel, in lifting the upper part of his own body, and in overcoming the inertia of earth, shovel and body. However, the theoretical ideal unit is the foot-pound, and, in selecting the actual unit to be used, the effort should be made to secure a unit that is as closely equivalent to the foot-pound as possible. Thus, in drilling, there are certain units of work done by the drill in pulverizing the rock in the drill hole, and this work is quite closely represented by the number of lineal feet of drill hole in any given kind of rock. Hence the most practical unit of work in drilling is the foot of hole drilled.

The second point to consider in selecting suitable units of work is the different processes involved. Each process on field contract work usually involves a different class of men. In rock excavation the six items above given usually involve six separate gangs of men. Although all contribute their part to the final contract unit upon which payment is received—the cubic yard—yet the work of each may be, and usually is, better measured in terms of some other unit. We already have seen that the lineal foot of drill hole—and not the cubic yard—is the unit to select for the drilling gang. The pound of explosive charged in the drill holes is a good unit by which to measure the work done by the blasting gang. The cubic yard of rock usually is the only practical unit of breaking large rock chunks. So, too, the cubic yard becomes the unit for loading and for dumping, whereas the yard-mile, or ton-mile, is made the unit of transportation. Still further subdivisions of some of these six processes are often desirable, yielding still other units that more closely approximate the foot-pound unit.

Therefore, our second rule is as follows: *Since construction usually is divided into processes, and since a separate gang usually performs each process, select sub-units based upon the work done by each gang.*

In order to apply this rule it frequently is necessary to reorganize the work so that each process is performed by its special gang. Where the work is not of sufficient magnitude to keep distinct gangs busy on each separate process, it is still often possible to work the same gang a few hours at one process and then shift it to another process, instead of working the same men in a heterogeneous fashion on two or more processes at the same time.

Units for Concrete Work.—The cost of a cubic yard of concrete varies between about $3.00 for cheap pavement sub-base to about $20.00 for certain parts of a reinforced concrete building. A hasty generalization drawn from such variations as this has led many an engineer to scout the usefulness of cost data, particularly such data as have not been gathered by the individual who attempts to draw conclusions from them. However, when the cubic yard of concrete is divided into proper sub-units of cost, it is astonishing to note the fading away of all seeming difficulties, either in estimating costs of concrete or in securing data upon which to judge the efficiency of workmen.

The labor processes in concrete may be classified as follows:

1. Receiving and storing materials.

2. Delivering materials to the mixer (loading and hauling).
3. Mixing concrete.
4. Transporting concrete.
5. Placing concrete.
6. Ramming concrete.
7. Finishing the surface.
8. Framing the lumber for forms.
9. Erecting forms.
10. Shifting and cleaning forms.
11. Taking down forms.
12. Shaping the reinforcing steel.
13. Placing the reinforcing steel.

Some of these processes may be still further subdivided, and frequently it is desirable to do so. While the cubic yard of concrete is usually a satisfactory unit for items one to six, it is clear that the square foot or square yard is a unit that must be used for item 7. Items 8 to 11 should be expressed in terms of the 1,000 ft. B. M. as the unit, and it is usually desirable also to use the square foot of concrete surface covered by forms used as another unit for estimating the cost of work on forms. Items 12 and 13 should be expressed in terms of the pound of steel as the unit, since the number of pounds of steel per cubic yard of concrete varies widely.

Two or More Units for the Same Class of Work.—As just indicated, it is frequently desirable to use more than one unit of measurement. The unit on which the contract price is based is usually a desirable one in which to express all items of cost. In addition to this, the cost of each item may be expressed in other units, such, for example, as the 1,000 ft. B. M. and the square foot of area for form work in concrete construction. Such units should be selected as will permit comparison not only of one day's work with another, but of one job with another, and frequently it is desirable to select units that may be used in comparing two entirely different classes of work.

Uniformity in Units of Measurement.—The economic importance of uniformity in units of measurement cannot be over-estimated. To illustrate: The common unit of concrete work is the cubic yard, but it is customary to measure cement walks in square feet. Now this leads to many blunders, not only in estimating the cost of walks, but in effecting reductions in cost. Not only does the thickness of cement walks vary widely, but the proportion of cement to sand in each layer of the walk is variable. Therefore, to say that it takes so many barrels of cement to make 100 sq. ft. of walk means next to nothing unless the plans and specifications for the walk are also given. For purposes of accurate estimating it is necessary to prepare tables of cost of mortars and concretes in terms of the cubic yard; then by remembering that 100 sq. ft. having a thickness of 1 inch are almost exactly 0.3 cu. yd., it is a simple matter to convert costs per cubic yard into costs per square foot.

Not only in computing costs of cement walks, and the like, but in

reducing costs, does it aid us to use the cubic yard as the unit, for it enables us to make comparisons, and thereby discover inefficiency of workers. Elsewhere in this book a case is cited where the labor cost of the face mortar for a concrete wall was out of all proportion to what it should have been. Had the contractor estimated the cost of this mortar in cubic yards, he would have discovered that it was excessive. The labor of mixing mortar should not be much greater than the labor of mixing concrete per cubic yard, nor should the labor of conveying the mortar in wheelbarrows be greater. The labor of placing it in a thin layer is obviously greater than for placing concrete in thick layers; but, in the case mentioned, the contractor was losing his money in mixing and conveying the mortar. He had not recognized the fact because he had not reduced the cost to dollars per cubic yard of mortar.

In like manner, one may often see money wasted in making and delivering mortar to bricklayers and masons, because the cost of the mortar itself, in terms of the cubic yard of mortar (not of masonry), has not been calculated.

The cost of labor on forms and falsework should always be recorded in terms of 1,000 ft. B. M., as the unit; for that is the common unit of timber work, and, being so, ready comparisons can be made only in dollars per M. ft. B. M.

It is surprising how few managers of men have realized the value of reducing the cost of each item of work to units that are comparable; and by this we mean units in terms of which entirely different classes of work may be compared. Thus, in a brick pavement there is grout used between the joints. This grout is a thin cement mortar, and it averages, let us say, 6 cents per sq. ft. of pavement. Now, what does it average per cubic yard of grout? Probably not one paving contractor in a thousand knows; but, until he does know, he cannot compare the cost of grouting with the cost of other kinds of cement work. Many a time have we had our eyes opened to unsuspected losses and inefficiencies only by reducing the costs of the elements of work to units comparable with the units of similar work in other fields.

The ton is a very convenient unit to use when comparing the cost of loading and handling materials of all kinds. The ton of brick, the ton of gravel, the ton of timber, the ton of cast-iron pipe, are loaded upon wagons by hand at a cost differing not so much, one from the other, as might at first be supposed. When reliable data are not available for estimating the cost of handling any given material, by reducing it to tons an approximate estimate can usually be made that will be satisfactory, at any rate far more reliable than a guess.

Units of Transportation.—On contract work, distances of transportation are usually so short that the percentage of time "lost" by cars, carts, etc., while being loaded, becomes a very large part of the total day's time. Hence the unit of transportation must not be simply a unit of weight, or of volume, transported a unit distance. For example, a wagon may be loaded with earth in 4½

minutes, transported 100 ft., dumped and returned in 1½ minutes, or less: total, 6 minutes. Of this time less than 25% is spent in transporting the earth. On the other hand, if the haul is 6,000 ft., the time spent in transporting may be 93%. The cost per 100 ft. transported is almost four times as much in one case as in the other. Therefore, unless the hauls are so long that the time lost in loading and unloading is an insignificant part of the total time, it is essential to divide the work of transportation into three elements:

1. Time lost loading.
2. Time lost transporting.
3. Time lost unloading.

Often this third item is so small that it may be disregarded. On contract work it is often necessary to have a fourth item:

4. Time lost during the shifting of tracks, and other changes in plant location.

In brief, the lost time, of whatsoever nature, must be determined and deducted from the total time, before the number of units of transportation performance can be divided by the correct number of hours.

Transportation, therefore, must be divided into two main units of cost:

1. Non-productive (lost time loading, dumping, shifting plant, etc.).
2. Productive.

The total cost of the non-productive time is divided by the total number of yards or tons moved to get the unit non-productive cost of transportation.

The productive cost of transportation is the ton-mile, the cubic yard-mile, the ton-station (station = 100 ft.), or the like.

The distance of transportation is usually computed from a map, but it is often desirable to attach an odometer to one, if not all, of the wagons, locomotives or the like.

Odometers of the kinds used on automobiles and bicycles can be advantageously used in a great many places on contract work, a few of which are as follows: On wagons, on wheel scrapers, on locomotives, on traction engines, on road rollers, on derricks (to record the number of swings), on hoisting engines, on cableway carriages, etc. Indeed, wherever a machine or tool has a revolving or reciprocating part, an odometer or counter can be used to record the number of reciprocations or revolutions, and from the data so recorded the amount of work can often be calculated with great accuracy.

Recording Single Units.—There are many classes of work in which the only practicable unit to be used is the single or individual unit itself; thus, the telegraph pole erected, the pile driven, the door hung, etc. Obviously records of units of this sort are so readily made as to require almost no comment.

A punch card is a convenient record of single units. Some contractors prefer a tally board on which each unit is marked or tal-

lied with a pencil. Others use a board like a cribbage board, having holes in which plugs are put to record the number of units. Still others give out tickets to the men for each unit of work delivered.

Record Cards Attached to Each Piece of Work.—In doing machine-shop work it is often necessary to have one piece of metal pass through the hands of several different workers. For example, one man may drill holes of a certain size, another man may drill holes of another size, still another man may thread the holes, and so on. In such a case it is common practice, where careful cost records are kept, to provide a card that is attached to each piece or each lot of pieces. In blanks provided on the card, each worker enters his number, and the number of hours and minutes spent by him in doing a specified kind of work on the piece. A modified form of this method is to attach a card or a brass check to each piece, giving a serial number and letter to the piece. Each workman on the piece notes its number on his own record card, and opposite this number be enters the amount of time spent on the piece.

While this method of recording output cannot be as frequently used in engineering contract work as in machine shop work, it should not be overlooked by the general contractor. It might well be applied to timber work where one gang of men bores the holes, another gang saws and a third gang "daps" or adzes the sticks, and so on. It is desirable always to assign different kinds of work to different men, not only because the time usually lost in changing tools may be saved, but because men become more expert when they do one class of work only. The record card facilitates the differentiation of labor into classes, and is, therefore, a great aid in increasing the output of a given number of men.

Measurements of Length.—For a great many kinds of contract work the lineal foot is the best unit to use. Track laying, fence building, pipe laying, setting curb, etc., come under this head. Many other classes of work are commonly measured only in terms of the lineal foot, when, to permit of true comparisons, some other unit or units should also be adopted. Sewer work, for example, is commonly recorded only in terms of the lineal foot; but the amount of excavation varies greatly per lineal foot in different sewers and often in the same sewer; hence the excavation should be measured with the cubic yard as the unit.

Tunnel excavation should also be reduced to the cubic yard standard. A contractor has no very definite idea whether the "mucking" (loading of cars) in a tunnel is being done economically or not until he has determined how many cubic yards each man is loading daily.

Measurements of length are often best made by driving a line of stakes 100 ft. apart, calling each stake a "station." The starting point or station is called Station o. The next station, 100 ft. from the start, is Sta. 1; the next station, 200 ft. from the start, is Sta. 2; and so on. Hence the mark on any given station stake gives the number of hundreds of feet from the starting point. Points intermediate—that is between any two stations—

are called "pluses." Thus, a point 40 ft. in advance of Sta. 2 is called "two plus forty," and is written Sta. 2 + 40, by which it is clear that it is 240 ft. from the start.

Having driven a line of station stakes, properly marked with their station number, a foreman or timekeeper can quickly ascertain the station and plus at which the day's work has been completed.

In many instances, measurements of length are best made by counting the number of pipe lengths laid, or the number of rail lengths.

Measurements of Area.—Paving, painting, roofing, plastering, and many other classes of construction work are best measured in terms of the square yard, square foot, or "square" (100 sq. ft.) as the unit. Since areas are usually measured with ease, it is noticeable that area work is generally done with much greater economy than mass work, which is usually more difficult to measure and consequently not measured every day on most jobs. It is sometimes not easy to measure the number of thousand feet board measure in concrete forms, in which case it may be preferable to measure the area of concrete covered by the forms, from which, if desired, the amount of lumber can be calculated approximately.

Measurements of Volume.—This class of measurements is usually the most difficult to make for purposes of daily output reports. Excavation, for example, is not easily measured, as a rule, except by a surveyor. Of massive masonry the same is true. Hence there are few contractors who know accurately how many cubic yards of this sort of work should be accredited each day to each gang. Record should be kept of the number of car or wagon loads of excavated material; but, to derive much benefit from such records, care must be taken to have cars and wagons of uniform size uniformly loaded, or to keep record of the capacities of the different vehicles. Where daily measurements of volume are difficult to secure, some one or more of the following methods may be adopted.

Measurements of Weight.—Loaded cars or wagons can be weighed on track scales or on portable platform scales, and this can be profitably done far oftener than it is. Loaded skips and buckets can be weighed with spring balances attached to the hoisting rope of a derrick. It is sometimes very difficult to measure volumes of certain quantities in the field and it then becomes of advantage to weigh them. It is not easy to tell how much rock there is on a skip load without weighing the loaded skip either by placing it on scales or by putting a spring balance on the derrick. Spring balances of that character can be purchased of a capacity up to 2,600 lbs. and costing about $150. Another form of rock measuring apparatus is in the nature of a balance, costing about $115. A great advantage of a spring balance on a derrick is that it takes no extra time for handling, and, while the first cost seems rather high, the information obtained on a large piece of work is well worth its cost.

In a good many of the Hudson River Trap Rock Quarries the stone is handled in cars which are pushed along on the tracks for purposes of weighing and the men are paid for performance according to the weights on the cars. This is a very accurate and, where it is practicable, a highly satisfactory method of measuring output.

This method has long been in use at coal mines where every car is numbered, and is weighed before dumping.

On contract work, such as macadamizing, for example, each wagon load may be weighed, if the amount of the work warrants the purchase and use of platform scales. It is usually considered sufficiently exact, however, to measure the size of a few loads, and simply count the number of loads. However, loads often vary so greatly in size that this method of counting loads becomes very unsatisfactory. This holds true particularly of loads of quarried stone, of earth loaded by steam shovels, and the like. In such cases the contractor should seriously consider the advisability of weighing each load.

One of the most difficult classes of construction work to measure daily is rubble masonry. Yet we have found two very satisfactory methods of recording the work done by each derrick gang. One way is to use wooden skips that are loaded at the quarry with stone, put upon cars and transported to the work. Each skip is provided with a clip for holding a brass check. The checks are numbered serially, and the weight of stone corresponding to each number is entered in a book; for before delivery to the masonry derricks each skip is lifted by a derrick, placed on scales and weighed. It is sometimes preferable to provide a large spring balance for weighing, instead of using scales. The mason in charge of the derrick gang removes the brass check from the skip and keeps it, entering its number on a card which is turned over to the timekeeper at night, together with the brass checks. Thus it is possible quickly to ascertain the number of tons of rubble laid by each gang.

Functional Units of Measure.—Under this head we class all measurements of units that are functions of the desired units. Thus, in any given mixture of concrete, the number of barrels or bags of cement is a function of (i. e., it bears a definite relation to) the number of cubic yards of concrete. Hence a record of the amount of cement used each day will enable making a close approximation to the number of cubic yards of concrete.

In rubble or cyclopean masonry, a record of the number of buckets of mortar will enable making a closo calculation of the yardage of masonry. If spalls are liberally used to reduce the amount of mortar, as they should be, then the number of buckets or skips of spalls should also be recorded.

The number of gallons of paint used is ordinarily a fair criterion of the area of surface painted.

By the use of packets for handling bricks, Gilbreth has developed a system of measuring the work done by each bricklayer, for count is made of the empty packets stacked up by each mason.

Since each packet is loaded with a definite number of bricks, this gives an accurate record of each man's output.

Stockpile Measurements.—There are certain kinds of construction that are best measured indirectly by ascertaining what has been removed each day from the stock piles. Thus, in erecting a frame building, the different kinds and sizes of lumber can be piled in stock piles of regular size, easily measured. Rolls of paper, bundles of shingles, etc., can be stored in such manner that a daily inventory of stock on hand is readily made. By subtracting the amount shown by the inventory at the end of each day from the amount on hand the previous day, an accurate record is obtained of materials that have gone into the building. Since a carpenter's work is usually best measured in terms of the 1,000 ft. B. M., the square of shingles, and the like, it is evident that stock pile measurements can be used to great advantage in determining the number of units of certain kinds of work performed on a building.

The measuring of material is greatly facilitated by using a standard method of handling. Gilbreth's rule for cement (see his "Field System") is to place the bags one on top of the other in piles of fifty.

One of the most difficult of the materials to check regularly is the reinforcing steel for concrete. If this is handled in plain bars they can be weighed and wired in bundles of 100 lbs., this being a suitable size for two men to carry. The bundles are, of course, nearly always more or less than 100 lbs., and when the steel is wired it is a good plan to attach to each bundle a tag giving its weight, which tag can be left with the storekeeper for record as the bundles are removed to the work. The difficulty of obtaining these records is caused by the fact that the material is usually placed in a haphazard way wherever it happens to be most convenient for the men placing it without any systematic regard for its use on the work.

Key Units of Measure.—It is always desirable to relieve the foreman or timekeeper of the work of computing the number of units of work done daily, wherever such computation involves either many measurements or much labor in computing. A foreman can readily report the number of "stations" of road graded or macadamized, leaving to the office force the work of deducing the number of units of work performed.

A further step in the same direction is the use of key letters and numbers to designate sections of work whose dimensions the foreman may not know but which are recorded in the office, and from which the number of units of work performed can be readily ascertained. For convenience we call these units key units, since they are designated by key letters or numbers.

Key Units on Drawings.—Any given structure can usually be divided into "sections" identical in shape and character of work. Thus, in a concrete building, there are a number of columns of identical size, a number of beams also identical, a number of

identical floor slabs, and so on. To each of these "sections" a key letter or number, or a combination letter and number, may be assigned and written on the drawing.

If numbers from 100 to 199 are reserved for "sections" on the first floor, and the letter C is used to denote columns, then C 100 will designate a particular kind of column on the first floor; while C 200 will designate a corresponding column on the second floor: Having assigned keys to all "sections," the foreman or timekeeper is furnished with blueprints on which the "sections" with their respective keys are marked. In some instances it is preferable to furnish only a few large blueprints containing many "sections" on each print, but it is usually desirable to supplement these large blueprints with small ones of notebook size, which, if preferred, can be punched and bound in a loose-leaf binder.

The foreman or timekeeper reports daily the number of each class of "sections" built by each gang, using the proper key to designate each "section." The office force, having computed the number of units of work in each section, is then able to record the total number of units of work done, with accuracy and with rapidity. If a full "section" is not completed, the foreman or timekeeper estimates the percentage completed, and reports accordingly.

Keys Marked on Separate Members.—On certain classes of work a modification of the above plan is preferable. Instead of providing the foreman or timekeeper with drawings having keyed "sections," a key number or letter is painted, or otherwise marked, on each separate member of the structure before it is put into place. Thus, each block of cut stone is measured in the stock yard and a "key" is painted upon it. Then, when the foreman reports that block A 105 has been laid in the wall, the office force can determine its volume from the recorded measurements. The authors have found this to be the most satisfactory method of recording cut stone work, for it is thus possible not merely to tell the total amount laid each day by several derrick gangs but to tell precisely what each gang has done, for each boss mason can be required to record the key number of every stone laid under his direction. The office work of computing the volume of each stone is insignificant in amount if tables are used for computation, such as Nash's "Expeditious Measurer" ($2.00). These tables give the volume of any block, progressing in size by inches up to 4 ft. 9 in. x 6 ft. 4 in. x 1 ft. 1 in. The tables also give surface areas, progressing by inches, up to 4 ft. 1 in. x 8 ft. 5 in. in size.

Structural steel members can be marked with key letters; so, too, can heavy timbers, moveable sections of forms and falsework, and many other classes of materials used in construction work.

Conclusion.—Upon the ingenuity of the management engineer who devises ways of recording the daily output of work done rests the success or failure of any effort to introduce modern methods of management on complicated contract work. The problem before him is often one to tax his ability almost to the elastic limit, for it is not sufficient to devise a method of measuring daily

output after a fashion. He must devise not only an accurate method but one that permits of application at the hands of men comparatively unskilled mentally, and under the varying conditions that characterize field construction work. Many a contractor has given up in disgust his attempt to install a modern system of cost keeping and has charged his failure to the folly of "new-fangled notions." Such failures are usually the outcome of trying to teach old dogs new tricks without so much as hiring a competent teacher. Eventually, it will be recognized that management engineering is a science not to be picked up and mastered at one reading of any article or book, but that it requires study extending over a considerable period of time.

Cost Keeping.—The following pages on cost keeping have been taken from "Cost Keeping and Management Engineering," by Gillette and Dana. In this brief summary here given it is obviously impossible to give more than general principles. For further elucidation of the subject by specific examples, the reader is referred to the book from which this abstract has been made.

The two primary objects of cost keeping are:

1. To enable a manager to analyze unit costs with a view to securing the minimum cost possible of attainment under existing conditions.

2. To provide data upon which to base estimates of the probable cost of projected work.

As a result of the analysis of unit costs, followed by a comparison of the items with corresponding cost items of similar work previously done, a manager may discover:

1. Excessive use of materials in erecting a given structure.

2. Excessive use of supplies (coal, etc.) in operating a plant, whether due to ignorance, carelessness or theft.

3. Inefficiency of workmen.

4. Inefficiency of foremen.

5. Padded payrolls.

6. Excessive loss of time due to: (a) plant breakdowns, (b) plant shifting, (c) waiting for materials or supplies, etc.

7. Improper design of plant.

Cost keeping also leads to the introduction of piece-rate or bonus systems of payment, which may, in fact, be said to be one of the ultimate objects of cost keeping.

Cost keeping secures many incidental advantages, like the following:

1. Fewer "bosses" are required on certain classes of work, for the report card is a more persuasive stimulus than the eye of a taskmaster.

2. One skilled manager can direct many more men, and with much greater effectiveness than is possible where a cost keeping system does not exist.

3. Systematic analysis of costs leads inevitably to a study of reasons for differences in costs, and this study of reasons is the first step toward inventing new machines and new methods for reducing costs.

Cost Keeping Defined.—For the purpose of the discussions in this book, a distinction must be drawn between bookkeeping and cost keeping.

Bookkeeping, as we treat it, is the process of recording commercial transactions for the purpose of showing debits and credits between different "accounts." These "accounts" may be individuals or firms, or they may be arbitrary accounts, the latter being an evolution in bookkeeping that came after individual accounts became so large or so complicated as to be insufficient to show the status of the business and the profits derived from any given transaction.

Cost keeping, as we treat it, is the process of recording the number of units of work and the number of units of materials entering into the production of any given structure, or into the performance of any given operation. To these units of work or materials, actual or arbitrary wages or prices may or may not be assigned. The object of cost keeping is primarily to show the efficiency of performance; hence actual money disbursements need not be recorded, as in bookkeeping. This distinction is vital, and will be discussed at greater length.

Differences Between Cost Keeping and Bookkeeping.—Bookkeeping was first devised and subsequently developed by merchants. Cost keeping was devised and developed by engineers. The merchant is a student of profits; the engineer is a student of costs. Although profits depend upon costs, there is a vast difference in the point of view of the merchant and the engineer.

In the study of costs, as we have previously pointed out, the aim of the engineer is to reduce all costs to a unit basis, selecting such units as most closely conform to the theoretical unit of work—the foot-pound. This study often necessitates the use of several different units for the same class of work. It necessitates the recording of conditions, and the making of measurements—all of which is more or less foreign to the fundamental idea of bookkeeping. Yet, in groping toward methods of cost keeping, it has become the practice of most contractors, manufacturers, railway companies, etc., to endeavor to develop a cost keeping system in the bookkeeping department. Hence we have to-day systems of bookkeeping that are wonderfully complex, and, withal, show very little that they attempt to show as to unit costs.

Take, for example, the accounting department of an American railway. Here we find skilled accountants loaded up with a mass of work called for in distributing the costs to different accounts. Calculating machines that carry the cost of railway spikes out to the third decimal place are clicking away from morning to night. A prodigious amount of figuring is done so that scores of distributions may be made, without the error of a cent in the balancing of accounts. Yet, with it all, what do these railway accounts show as to unit costs? Next to nothing worthy of the name of cost keeping. The authors have in their possession a mass of railway accounting records; some of it of great value, but most of it valuable only to show bookkeeping gone mad. The accounting department of the average railway has no true record of unit costs.

The average railway engineering department is even worse off, as shown by the ridiculous estimates often submitted. After a structure is built, the auditor of the railway takes the superintendent of construction to account for having exceeded the engineer's estimate. The engineer is put on the rack and calls the superintendent inefficient—which is usually true. The superintendent retorts, in his letter to the accounting department, that the engineer does not know how to estimate correctly—which, also, is usually true. Figures, figures, figures, but not a single unit cost! This is typical of railway accounting costs to-day. We emphasize it because it is also typical of the accounting departments of many contracting firms. And we emphasize it again because it illustrates so well our contention that bookkeeping and cost keeping must be divorced if there is to be a simple, effective system of ascertaining the efficiency of workmen, and permit of such study of their performance as will result in greater efficiency.

We shall now give in concise form some of the various reasons why cost keeping records should be kept entirely distinct from bookkeeping records.

1. Since the primary object of *bookkeeping* is to show debits and credits, all accounts must be summarized in one book—the ledger. Since the primary object of *cost keeping* is to reduce costs, no book corresponding to a ledger is needed. Indeed it is often desirable to have cost records of different classes of work kept in different books, in different ways, by different men, in order to localize responsibility as well as to apply different units as standards of comparison.

2. *Cost keeping* should partake of the nature of daily reports by which a superintendent can gage the daily performance, and discover inefficiency at once. *Bookkeeping* accounts may not be, and usually are not, posted promptly or completely until some time subsequent to any performance.

3. *Bookkeeping* records must balance to a penny. *Cost keeping* records need not be kept with mathematical precision, except in so far as bonus payments to workmen are involved. The object of cost keeping is to show efficiency, and this may usually be shown by approximations fully as well as by hair splitting exactness. Hence cost keeping records may be devised that will require far less clerical work than is necessary when mathematically accurate bookkeeping is used.

4. *Bookkeeping* is a clerical function; *cost keeping* is an engineering function. It is a rule of successful management not to ask one man to exercise many functions, particularly when they are diverse in nature. An engineer is not interested in recording debits and credits, or in the rendering of bills—functions of the bookkeeper. On the contrary, a bookkeeper knows nothing about construction methods and not only has little interest in construction costs, but lacks the necessary engineering training to interpret cost records and to devise methods of reducing costs.

5. A contractor who has an effective and simple system of bookkeeping naturally objects to a change to a more complex sys-

tem, such as is necessary when cost keeping is added to the bookkeeper's duties.

6. When cost keeping is begun, it is well to start in a small way, taking some particular kind of work, like teaming, and applying a system of daily reports. When this phase of the work has been analyzed and organized, some other feature is taken up, and so on, thus developing a cost keeping system gradually. Resistance to change is bound to be encountered, and the way to overcome it is in this manner, a little at a time. Bookkeeping cannot be changed a little at a time. A new system of bookkeeping means an entire revision all at once, for accounts are interdependent.

7. Cost keeping records should state conditions, such as weather, distance of haul, etc., which are essential to interpretation of results. Sketches showing design of structures should form part of permanent cost records. Such things are entirely foreign to bookkeeping, and, if placed upon bookkeeping records, simply serve to confuse them.

8. The bookkeeper enters bills for materials as they are received, crediting the firm that furnishes them. A barrel of spikes may be followed by a dozen picks on the bill. It is not the bookkeeper's function to trace the spikes to their place in the work, and, when the work is finished, to ascertain the total number of barrels of spikes used in a particular structure. That is the function of the cost keeper on the ground. The bookkeeper must show that John Smith Co. has been credited with the spikes. The cost keeper, on the other hand, cares nothing as to the particular firm credited. He is concerned only with the quantity of spikes and the use to which they have been put. It is hopelessly confusing to try to show in one set of records both credits, and unit costs.

9. In studying cost records to ascertain efficiency, it is often necessary to have several different units as standards. On reinforced concrete work, for example, the primary unit is the cubic yard, but there should be at least three other units, namely, the pound of steel (for comparing costs of handling and placing the steel reinforcement), the thousand feet B. M. (for comparing costs of forms), and the square foot of exposed surface (not only for comparing costs of form work but costs of surface dressing). Cost records must be sufficiently detailed for these purposes, if not in every case, at least in some cases of concrete work. Bookkeeping records become hopeless of interpretation unless they are uniform, and, to be uniform, they must have few units of comparison. In brief, bookkeeping is not flexible. To generalize further, cost keeping costs must be divided by units of work done, so as to secure unit costs for comparison, which is a process foreign to bookkeeping.

10. Since cost keeping has as its primary object the reduction of costs, since comparison of results secured by different men or different machines or different methods are necessary, it follows that standard wages and standard prices of materials must be used. It may happen that on one job the cement may be purchased at different times at prices ranging from $1.20 to $1.50 per barrel, and that common laborers may receive from $1.50 to $1.75 a day.

In comparing unit costs a standard price of cement should be assumed, as $1.30 per barrel, and a common labor standard wage, as $1.50 per day Then comparisons become possible. A bookkeeper cannot assume any rate of wage or any price; he must give the actual wage or price. A cost keeper usually finds it desirable to use standard wages or prices which approximate the average, or actually are the average.

Time Keeping Defined.—Time keeping, in its old fashioned sense, is a part of the bookkeeping system, and the timekeeper is charged with the task of ascertaining what time each man has worked during the day, week or month, according to the arrangement under which he is employed, and what amount of money is due him on pay-day. The timekeeper was not concerned with how much work a man did or on what process his time was spent, so long as the general distribution of the work was obtained. Of late years the timekeeper's distributions have become much more elaborate and now he is often charged with considerable cost keeping responsibility. When he does cost keeping work, the records should ordinarily be kept on separate blanks from the time keeping.

If a timekeeper, unaided, attempts to distribute the labor according to the work done, his records become complex and are rarely reliable, for, due to his going from place to place, he must rely upon what others (like foremen) tell him as to the performance of different men. In his attempt to balance the statements made to him with the total time, he usually "fudges" his distributed records.

Daily Cost Reports, By Whom Made.—Daily cost reports may be made by: (a) individual workmen, (b) foremen, or (c) timekeepers, or by all three of these classes of employes.

Individual workmen are not always competent to fill out reports properly, but, if the report is simple in form and relates to work done by "skilled workmen," it is usually possible to get very satisfactory results. Certainly the individual report is to be encouraged wherever it can be applied, for it heightens the individual's interest in his work.

On field contract work the foreman is the man usually required to make the daily reports. His constant presence on the work enables him to make a more accurate report than a timekeeper can make, if the timekeeper is required to cover considerable territory, as is usually the case.

In addition to his duty in keeping the time of the men for purposes of paying them properly, the timekeeper is often able to attend to filling out the daily cost reports, or one or more special timekeepers may be appointed for the special purpose of rendering daily cost reports. If the timekeeper is not able to be present constantly where a gang is at work, it is often wise to prepare certain blanks upon which he receives reports from the foreman of the gang, and, from this foreman reports and reports of individuals, combined with his own observations and measurements, the timekeeper is able to fill out the complete report.

No hard and fast rule can be laid down as to the best persons

to whom report making is to be entrusted. The character of the workmen, the size of the job, and other conditions govern the choice.

Written Card vs. Punch Card Reports.—Daily cost reports are best made on forms or blanks, and these forms are preferably cards in which the blank spaces are marked either in writing or by punching holes with a conductor's punch. The written card possesses the following advantages over the punch card:

1. It is more flexible, because the punch card is limited in the scope of the record to what has been foreseen in the office plus what can be written in a small space reserved for remarks. The pad and pencil are not so limited.

2. A man can usually go ahead filling out blanks in a written card without any previous directions, while he has to have some instruction in the use of the punch.

3. Erasures are possible with pencil and pad but not with a punch card. This is not always an advantage on the side of the written card, however.

The punch card possesses the following advantages over the written card:

1. By folding the card, or by superimposing one card on another, a duplicate record is secured without the use of the carbon paper necessary to secure duplicates with written cards. This duplicate record cannot be altered or erased, and one copy may be kept by the superintendent for his record in discussing the work with the home office, the other being sent in as a regular report to the proper department.

2. A dirty thumb can greatly interfere with the legibility of a written record. Moreover the average foreman or time keeper does not write a particularly clear hand. Punch card records are absolutely clear and legible.

3. It is sometimes expedient to have records from two or more men on the same card. By having no two punches alike on the job and having each man's punch charged to his name on the records it is possible to have a clear and complete record of who made the record without wasting time and space for signatures.

4. The hole made by the punch is usually less than one-eighth of an inch in diameter, and consequently a much larger number of facts can be recorded upon a small card by the punch than by writing, the number of groups of facts, however, being somewhat limited.

5. To punch a hole in a card takes much less time than to make the average pencil record, especially where duplicate records are made. Where a time keeper has to keep track of a large number of men this is a very valuable feature.

6. A hole can be accurately punched while riding on a hand-car, wagon or locomotive, when the vibration would greatly distort a man's handwriting.

7. Punch cards can be made on blue print paper from a tracing, which is an advantage where a mimeograph is not available for making white cards to be filled in with pencil.

Time Cards that Show Changes of Occupation.—In field contract work there is usually more or less change of occupation constantly occurring. A gang of workmen may be engaged in grading for a while and then may be shifted to track laying; or at least some individual in the gang may be thus shifted from one class of work to another. Hence it is usually desirable to have daily report cards arranged so as to record the exact amount of time spent by each individual on each class of work. This may be accomplished in either one of two ways: First, by having a separate card for each workman; or, second, by having a gang card on which each workman's name or number appears, and so arranged that his time may be placed opposite or under the tabulated class of work that he has performed.

The individual card (a card for each workman) is often preferable when the bonus system, or its equivalent, is employed. On most contract work, however, the bonus system is not yet in operation, and gang cards, filled in by the foreman, will serve the purpose of showing the total performance of the gang and the times spent by the various individuals on different work. There are several ways of recording the individual times spent by men working in a gang, among which the following are typical.

Each employee is given a number, and the numbers are arranged in a horizontal line across the top of a time sheet, as shown in Fig. 4. The different classes of work are printed in a column at the left, one line being assigned to each subclass. If team No 1 works from 7 to 9 a. m. plowing, the record is made by the foreman, who writes 7-9 opposite "Plowing" and under No. 1; since this is 2 hours' work, the figure 2 is subsequently written directly below the 7-9. If team No. 1 is then transferred to work connected with rolling subgrade, and is thus engaged from 9 to 11 a. m., this fact is indicated, as shown, by writing 9-11 under No. 1 and opposite "Rolling Subgrade."

Another method involves the use of "key letters" to indicate each class of work, the proper key letter being placed opposite the employee's name and under the nearest half hour when he began doing the class of work represented by the key letter. Fig. 5 shows that employee No. 1, whose name is Smith, began work at 7 a. m., the key letter *A* being under 7, and that he was engaged in excavation, since *A* is the "key" for excavation. He continued on excavation until 10:30 a. m., when he began backfilling, as shown by the key letter *C* entered under 10 and in the lower square. The upper squares indicate the even hour, and the lower squares indicate the half hour. At 3 p. m. he was transferred to concrete work, as shown by the key letter F under 3, where it will be seen that the number of hours worked by each man on each class of work is recorded under a column headed with a combination of key letters that indicate the class of work.

Wherever men are being frequently shifted from one class of work to another, some method of recording the time of shifting, at least to the nearest half hour, should be used, as outlined in the different ways above given. If a foreman does not make an imme-

diate record of such shifting, but relies upon his memory to fill in his report blanks at night, he is almost certain to make serious

Street __________ Date __________ 190__ City __________

	No. OF EMPLOYEE	1	2	3	27	28	29	30	31	32	33	Total Hours
GRADING	Plowing	7-9 2										
	Excavating											
	Rolling Subgrade	9-11 2										
CONCRETE BASE	Hauling & Loading Concrete Gravel	11-12 1										
	Hauling & Loading Concrete Stone											
	Hauling & Loading Concrete Sand											
	Laying Concrete											
	Hauling & Unloading Cement											
BRICK	Hauling & Unloading	1-6 5										
	Laying Brick		7-8 1									
	Making Cushion		8-12 4									
	Hauling & Loading Cushion Sand											
	Culling Brick		1-3 2									
	Rolling Brick											
FILLER	Putting in Filler		3-6 3									
	Hauling & Loading Filler Sand											
	Putting in Expansion Joints											
SEWERAGE	Putting in Sewers & Inlets											
	Putting in Catch Basins											
	Putting in Manholes											
SAND	Screening Sand											
CURBING	Hauling & Loading Gravel or Stone											
	Hauling & Loading Sand											
	Hauling and Unloading Cement											
SUNDRIES	Hauling & Loading filling Gravel or Sand											
	Cleaning up											
	General											
MACADAM	Rolling Stone											
	Spreading Stone											
	Total Hours	10	10									
	Rate Per Hour	35	20									

All remarks must appear on the other side

Foreman

Fig. 4. Time Sheet.

mistakes. Moreover, it is not unusual for a foreman to "fudge" the reports thus made, and even to falsify them grossly, for the purpose of showing a seemingly high efficiency of the men on certain

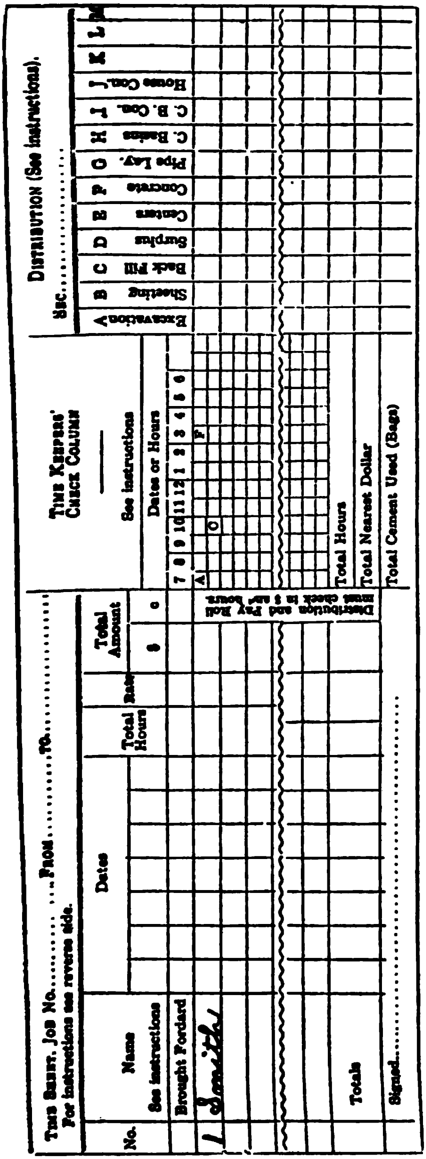


Fig. 5. Time Sheet.

classes of work; but, if a blank must be filled in during the progress of the work, and not at night, a foreman risks discovery of any attempted deceit, since his record card may be examined at an unexpected time of the day.

Gang Report Cards.—These are usually made by the foreman in charge of the gang. If the gang is always engaged on the same class of work, it is not necessary for the foreman to keep a time record of each man's occupation, in the manner just described; for the foreman can fill in the daily report card from memory. In this case the *timekeeper* records each workman's name and hours of work, while the *foreman* concerns himself only with reporting the total number of men engaged on each class of work and their day's performance.

A gang report card should usually show most of the following things:

1. Number of contract.
2. Location of the job.
3. Character of the job.
4. Date of the report.
5. Kind of weather.
6. Name of the foreman.
7. Classification of work, or "key letters."
8. Total hours labor under each class.
9. Rates per hour.
10. Total pay.
11. Number of units of each class of work done.
12. Units of material and supplies used.
13. Units of materials received.
14. Units of material in stock.
15. Delays, time and cause.
16. Time machines are actually working.
17. Kind of machine or tool used and its condition.
18. Remarks.

Obviously there are many classes of work that do not require a daily statement containing all these 17 facts; but in preparing a daily report card it is desirable to have this list at hand, to make sure that no omissions occur.

The space reserved for "Remarks" is usually so small that it is rarely used. Special conditions that would naturally be recorded under "Remarks" had better be recorded in a loose leaf diary kept by the foreman, of which more will be said later.

In designing a gang report card, the most difficult feature is the classification. This, however, is greatly simplified if done according to the following system:

1. Select for the general class heads the items upon which the unit contract prices are based, such as excavation (cu. yds.), macadam (sq. yds.), curb (lin. ft.).

2. Divide each of these pay items into the *operations* involved. Thus excavation involves (a) loosening, (b) loading, (c) transporting, and (d) dumping.

3. Divide each operation into as many subheadings as there are

classes of workmen engaged upon it. Thus, the operation of loosening earth may involve (a) teams plowing, and (b) men holding plow.

Summing up we would have the following subclasses under the class Excavation:

Excavation—
  Loosening: Men holding plow.
    Teams plowing.
  Loading: Men shoveling.
  Transporting: Teams.
  Dumping: Men.

The next thing to consider is whether the men are of the same class, receiving the same rates of wages; for, if they are not, there must be a further subdivision. For example, on cement curb construction, the classification would be as follows:

Curb—
  Trenching: Laborers.
  Placing cinders: Laborers.
  Mixing and placing: Laborers.
  Setting forms: Skilled laborers.
  Finishing: Skilled finishers.
    Helpers.

There are many kinds of pay items, such as macadam, that often involve processes that are performed at widely separated places. Thus, quarrying and crushing are processes far removed from spreading, rolling and sprinkling the macadam. Whenever this is the case, it is usually unwise to attempt to show all the processes on one report card. A good general rule to follow is to group together on the same report card only those processes that come directly and constantly under the eye of one foreman. Therefore one report card should show the quarrying and crushing, another should show the grading of the road; and possibly the spreading, rolling and sprinkling of the macadam should also be placed upon the same card with the grading, but not unless the grading gang is to be always a very short distance in advance of the macadamizing.

The commonest mistake in designing report blanks is to endeavor to reduce the number of the blanks. It is far better to have more blanks and to distribute the work of reporting, for it not only simplifies the blanks, but, by giving each foreman less to report, greater accuracy is secured. In fact, there are many operations that can best be reported by the workmen themselves. Thus, to continue the illustration of the macadam road work, each of the teamsters hauling broken stone should carry an individual report card which is punched or marked by workmen at each end of the trip.

We have said that the pay items should be analyzed according to the operation involved, but care must be taken not to select operations upon which men are engaged for but a few moments continuously. To illustrate: In mixing concrete by hand, there are usually the following operations: (a) loading wheelbarrows, (b)

wheeling, (c) mixing, (d) loading, (e) transporting, (f) spreading and ramming. Some gangs are so organized that a few men are kept constantly busy loading wheelbarrows with sand and stone, while the rest of the gang spends a few minutes wheeling, a few more mixing, and so on. Clearly it would be foolish to subdivide the operations on the report cards where the organization is of this character, for most of the men are changing their operations so frequently that a foreman would have time left for doing nothing but to record their changes.

We see that the designer of a report blank should know approximately what the organization of the gang and what the methods of operation are to be, before he can design a report blank that will be concise, and complete, but with no superfluous headings. Since there are almost innumerable methods of doing work, it is obviously impossible to furnish a set of printed report cards that will exactly serve all cases, unless the classification headings used are very general. However, the designing of a report card is a comparatively simple matter once the organization and methods of doing the work are known, provided the foregoing system is used.

A tentative report blank can be designed either by using some existing report card for similar work as a guide, or by referring to some book that gives, in detail, the costs of construction work similar to that for which the report blank is intended. From the items of cost given in published records, a classification can be prepared that will be of decided help in planning the report card.

In order to economize space on a report blank, it is not always necessary to print the classes or subclasses in full. Abbreviations and key letters may be used. Sometimes the mere recording of the rate of wages opposite a class will show the subclass. Thus, under the class of "Forms" (building wooden forms for concrete) if a wage of 20 cts. per hour appears, also a wage of 35 cts. per hour, it will be understood that the latter refers to the carpenter, while the former refers to the carpenter's helper.

Having decided upon the classification of operations and employes, the next thing to determine is the character of the performance report which is usually to be recorded on the same card.

We have discussed the difficulties of reporting daily performance, and have indicated ways of overcoming the difficulties. It is evident that a foreman or timekeeper should not be expected to report the number of units of each class of work performed if any considerable amount of difficult measurement is involved. Hence, it is usually futile to provide for a daily report of the number of cubic yards of earth excavated. On the other hand, the number of wagon loads, or car loads, may usually be reported, and the blank used for excavation should usually provide for such a report.

If some of the excavated material is shoveled directly into the embankment or hauled by scrapers, while some is hauled by wagons, it will be futile to provide for a daily report of loads hauled. In such cases, it is often advisable to report merely the number of lineal feet of work done daily. Thus, in road work, where the excavation is shallow and mostly from ditches, the

report should show the station and plus up to which the grading is completed at the end of the day. It is then the function of the office force to determine the yardage from the office records.

The amount of concrete and cement work of all kinds can be reported with considerable accuracy by stating the number of bags of cement used during the day.

The amount of supplies, like coal, used each day, can usually be reported if some system is devised for recording consumption or for readily inventorying the stock on hand each night. It is generally wise to require coal to be measured in boxes or in wheelbarrows of uniform size, uniformly filled. Then each fireman reports the number of cubic feet (or boxes) of coal used during the day.

Empty dynamite boxes are often convenient for purposes of measurement, as they hold exactly ¾ cu. ft. each.

Individual Record Cards.—Wherever individual workmen are paid by the bonus or price rate systems, it is usually best to provide a separate record card for each workman, for it is difficult to make a compact record on one card that will show not only the occupations of a number of men, but the performance of each man. This is particularly true where the men are repeatedly shifted from one class of work to another.

Where one man operates a machine, like a rock drill, it is usually wise to provide him with his own individual record card, upon which he is required to record his day's performance. A modification of this plan is to let the foreman carry the individual records of all the men, and fill in each card himself.

The engineman on a dinky locomotive should be required to make and fill in a daily report, showing the number of train loads hauled, time lost, etc.

A teamster should usually be required to carry a card whereon are recorded the times of arrival or departure at each end of each trip.

A steam roller engineman should be required to fill in a card report showing number of lineal feet of road rolled, and the number of miles traveled by the roller. The latter should be recorded by an odometer.

Kind of Punches to Use.—If punch card reports are to be used, an ordinary conductor's punch will serve for small cards; but it is generally desirable to have large cards, which necessitates the use of a special punch having a 2-in. reach. Such special punches are made by L. A. Sayre & Co., of Newark, N. J., and by other railroad supply concerns.

Size and Kind of Daily Report Cards.—It is usually desirable to have report cards of a size that will be suitable for filing in the standard card index files. A size that will be found satisfactory for general use is 5 x 7¾ ins.

If reports are to be written and made out in duplicate, the report cards should be made up in pads of alternate thin and thick cards, so that a carbon paper may be inserted between a thin card and a thick one.

It is generally wise to have the cards tinted one color for the original and another color for the duplicate. It is also a good plan to designate the kind of report card by a key letter, or combination of letters, which may be stamped in red in one corner of the card. Thus the letter T may be used to designate the daily report card of teamsters. Instead of using mnemonic key letters, some contractors prefer to use different tints for different classes of report cards.

This works well when there are only a few classes, but becomes confusing when there are many, and is worthless as a means of distinguishing cards at a glance when there are very many classes.

Where a great deal of information must be crowded on one card, it is often desirable to provide for writing the report on both

Team M. Sheehan No. 2. Day Aug. 1. 1907.

6	0	5	10	15	20	25	30	35	40	45	50	55
7		◆										
8					✚							
9												
10												
11												
12												
1												
2												
3												
4												
5												
6												

Length of Haul ....

Fig. 6. Punch Card For Teams.

faces of the card. This is objectionable, however, because it makes it impracticable to produce a duplicate by the use of carbon paper. It is also inconvenient to examine such a card after it is placed in a filing case.

Foreman's Diary.—The foreman or the superintendent should usually be required to keep a daily diary in which should be entered:

1. Verbal orders received from engineers and owners.
2. Verbal requests made to the engineers for grade stakes, etc.
3. Weather conditions.
4. Remarks as to hardness of digging, poor quality of materials and supplies, slowness of their delivery, general inefficiency of the men available, and such other conditions as bear upon the eco-

nomic performance of the work but can not be shown in the daily report.

The ordinary field foreman will not keep a diary of much value unless its pages are inspected daily. This requires that it shall be a duplicate loose leaf diary, the original leaf being sent to the office with the daily cost report, and the duplicate, or carbon copy, being retained by the foreman and bound in a loose leaf binder.

Designing Punch Card Reports.—We have already enumerated the advantages of the punch card for certain kinds of daily reports. One of the earliest punch cards devised for this purpose is shown in Fig. 6, and was designed by one of the authors for recording the daily work done by each team in hauling broken stone for macadam. Each teamster carries a card which he presents for punching at each end of the trip. The diamond punch hole indicates that the loaded team left the crusher bin at 7:05 a. m. The cross punch holes shows that it dumped its load on the road at 8:20 a. m. A new card is issued to each teamster each day; but, if it is desired to provide one card that will serve for a full week, one is easily designed.

A more elaborate form of individual punch card is shown in Fig. 7, and is designed to show the daily performance of each rock drill in great detail and in duplicate. Note that the upper half of the card is to be folded back on the lower half, so that the holes are punched in duplicate.

The punch holes in this particular card show:

1. That the holes were spaced 4 ft. one way and 5 ft. the other.
2. That + bits were used.
3. That the drill was in good condition.
4. That the drill was No. 2.
5. That a 3-in. starting bit was used.
6. That 54 ft. of hole were drilled.
7. That there were 4 holes, Nos. 1, 2, 3 and 4, whose depths were 15, 14, 13 and 12 ft., respectively.

(Note: A hole, No. 0, is provided, in case a partly drilled hole of the previous day has to be completed, for, in that event, the number of feet drilled to complete the hole is punched above hole No. 0.)

8. That the date was July 16.
9. That work began at 7:02 a. m., and hole No. 1 was completed at 9:44; that work was stopped at 12 m. and begun again at 1 p. m.; that hole No. 2 was finished at 1:18 p. m., hole No. 3 at 2:36, hole No. 4 at 4:52.

It is not usually necessary to record rock drill operations to the nearest even minute, as the nearest 5 minutes will ordinarily suffice; but it is sometimes desirable to have the drillers record the time of starting one hole and of starting the next hole. In that case this card, which provides for a time record on 2-min. intervals, is more satisfactory than one designed for 5-min. intervals. Drillers are often very slow in shifting drills from one hole to the next, which is well shown up if the time of finishing one hole and of starting the next is punched. Punching two holes in the card in one

square (punching double), can be used to indicate time of starting a hole, while punching one hole indicates its time of completion.

Note that in designing punch cards, space can be economized by the arrangement shown in the upper left hand corner of Fig. 7

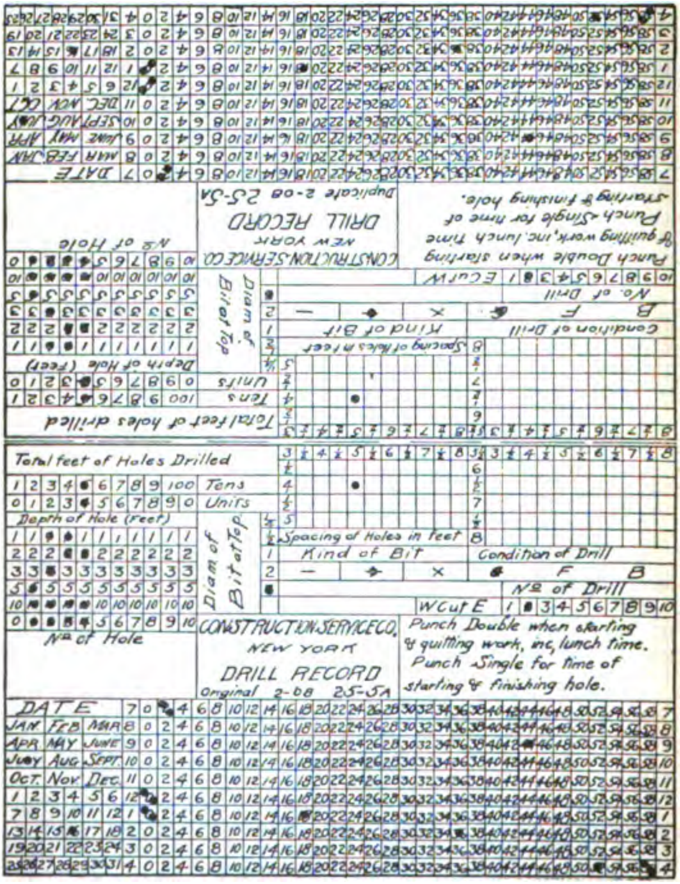


Fig. 7. Duplicate Punch Card.

where the upper line indicates "tens" and the lower line indicates "units."

On some classes of work, particularly shop work, it is often de-

sirable to have a separate punch card for each class of work, instead of recording several classes of work on the same card. Fig. 8 illustrates such a card that has been used by the National Switch & Signal Co. and was described by Mr. Chas. Hansel and published in the "Complete Cost Keeper," 1903. Each workman perforates the 5-min. time card for each job on which he is employed, simply piercing the card at the 5-min. points most nearly representing his times of beginning and ending work on the job in hand, the appropriate order number being entered on the card by the foreman. When the workman enters the shop in the morning, he is furnished with one time card, which he hangs on the upper hook of his individual time board, after perforating it at his beginning time. If the foreman gives the workman a second job before the first is completed, he fills in the order number on a second card,

TIME CARD

Workman's No........ Date.,..........

Date Commenced ....

Order No........................

Catalog No.........................

Number Pieces ....

Operation No....................

Date Finished...................

H	Min.										
7	5	10	15	20	25	30	35	40	45	50	55
8	5	10	15	20	25	30	35	40	45	50	55
9	5	10	15	20	25	30	35	40	45	50	55
10	5	10	15	20	25	30	35	40	45	50	55
11	5	10	15	20	25	30	35	40	45	50	55
12	5	10	15	20	25	30	35	40	45	50	55
1	5	10	15	20	25	30	35	40	45	50	55
2	5	10	15	20	25	30	35	40	45	50	55
3	5	10	15	20	25	30	35	40	45	50	55
4	5	10	15	20	25	30	35	40	45	50	55
5	5	10	15	20	25	30	35	40	45	50	55
6	5	10	15	20	25	30	35	40	45	50	55

Approved

............................Foreman

Fig. 8. Punch Card.

and hangs this second card on the upper hook. Thus the workman may have any number of jobs before him, each order being given on a separate card. When any job is completed its card is transferred to the lower hook. The time cards on the lower hook are removed by the timekeeper each morning, cards on the upper hook being left undisturbed.

Record Cards Accompanying Each Piece of Work.—In doing machine shop work, it is often necessary to have one piece of metal pass through the hands of several workers. For example, one man may drill holes of a certain size, another may drill holes of another size, still another may thread the holes, and so on. In

such a case a record card may be attached to, or accompany each piece or lot of pieces. In blanks provided on the card, each worker enters his number and the amount of time spent in doing a specified kind and amount of work on the piece.

Using Several Record Cards, One For Each Piece of Work.—A method that is usually preferable to the one just described for shop work, is to give each workman several record cards. As each new piece of work comes to him, he enters its "order number" on a record card, and records the time he spends on the piece. When finished, he uses another record card for the next piece.

Store Keeper's Reports.—The store keeper's duties include the following:

1. He must receipt for and take charge of all material delivered for temporary storage.
2. He must see that all of this material is properly accounted for and none lost or stolen.
3. He must take charge of the issuing of materials and supplies to the men and see that they are issued in proper quantity and that there is no waste.
4. He should see that needed material and supplies are issued without loss of time.

To accomplish these objects it is necessary that some one be on hand at the store house at all times when material is likely to be delivered or called for. This includes the noon hour as well as other times. Considerable economy results from sending to the store house in the noon hour to obtain articles that are needed in the afternoon.

The second duty of the storekeeper is often interfered with by men going to the store house for articles needed in a hurry and not leaving receipts for them. The only way, then, that the storekeeper can account for his materials would be by periodical inventories, and then at the best there is nothing whereby the periodical inventory can be checked. The perfunctory inventory is generally useless. All the men in the field in the position of authority or who are likely to require to have materials issued to them should be provided with small requisition blanks, and the storekeeper should require a requisition slip as a receipt for all material issued.

At the end of the month these receipts for material issued should tally with his inventory and list of material received.

Reports on Materials and Supplies.—Fig. 9 is a card for reporting supplies received. It includes the oil, waste, powder, caps and fuse supplied to the various field organizations, such as drillers, pumps, various steam shovels, dinkeys, cars, shovels, and also shows the amount remaining on hand. This is for steam shovel work in rock.

Fig. 10 is material card designed to be used daily by the foreman on concrete work for recording the materials received. The size of various loads of cement, gravel, sand, screenings, stone, and the number of feet board measure of lumber are shown on one half of the card, and on the other half are the amounts of glass, steel,

SUPPLY REPORT NO. 1. ....190....

	Drillers.	Pumps.	No. 1 Shovel.	No. 2 Shovel.	No. 1 Dinkey.	No. 2 Dinkey.	No. 3 Dinkey.	Cars.	Shop.	Little Hill.	On Hand.
Cyl. Oil....											
Eng. "											
Blk. "											
Waste											
Powder....											
Dynamite.											
Exploders.											
Caps.....											
Fuse.....											

Fig. 9. Supply Report.

Job No. MATERIALS RECEIVED

Date 190 Foreman

Size or Brand		From Whom Received	Size or Brand		From Whom Received
bbls.	Cement		bbls.	Glass	
bags	"		bars	Steel	
yds.	Gravel		"	"	
"	Sand		"	"	
"	Screenings		"	"	
lbs.	Stone		lbs.	Lampblack	
"	"		"	Oakum	
yds.	Sand		"	Nails	
ft.	Lumber				

Fig. 10. Materials Report.

lampblack, oakum, nails, etc. On the back of the card an entry is supposed to be made of all material sent away from the shop or remaining on the work at night, thus giving a check upon the quantity of materials used.

Checking the Accuracy of Reports.—Systematic checking of the accuracy of reports made by individuals or foremen is of paramount importance, for, unless this is done, there is apt to be gross falsification of the reports in order to make a favorable showing of performance. Thus, if a drill runner is not checked occasionally as to his report of number of feet drilled, he is apt to add several feet to his actual performance.

On one railway with which the authors are familiar, the master mechanic is in the habit of reporting the time of men spent in building new cars as if it were spent in repairing old cars. The object in doing this is to make a creditable showing of the cost of making new equipment. While it is true that this seems like robbing Peter to pay Paul, it must be remembered that there is usually great difficulty in determining just what is a reasonable cost of repairing a car, whereas there is no difficulty in fixing upon a reasonable cost of making a new car.

So many men are dishonest, particularly in ways that are not actually criminal, that implicit trust should not be placed in reports that are not verified by systematic investigation at unexpected intervals of time, if they are not subject to constant checking.

On construction work it should be the duty of someone to make reports that will check the reports made by individual workmen and by foremen. The timekeeper is usually the man upon whom part of this checking devolves. Thus, the timekeeper may be required to make certain measurements at the close of the day, from which a foreman's report of performance can be checked, as, for example, the number of drill holes and the depth of each. The timekeeper may also be required to visit each part of the work frequently, noting the number of men engaged in each class of work at the time of each visit. Frequent visits are often made possible by providing the timekeeper with a horse or a motorcycle.

Checking the distribution of the men of a gang, as well as observing the energy with which they are working, may frequently be done to advantage by means of a telescope or field glasses in the hands of an observer located in a tower or on some high point of ground.

By requiring different foremen and different individuals to report on the same performance, an excellent check can often be secured. Thus, the dinkey locomotive engineman should report the number of trains hauled, and either the dump foreman or the steam shovel engineman should render a similar report.

The monthly estimates of engineers should, of course, be used to check the daily reports of foremen, as far as possible; and on large jobs it is often desirable for a contractor to employ engineers to cross-section and measure the work once a week, if not more frequently.

Where the gang under a foreman is frequently shifted from one class of work to another, the foreman should always record the time that the change is made, in one of the ways already indicated. When this is done, the superintendent or walking boss should examine the foreman's record occasionally, during the day—not necessarily every day—to assure himself that the foreman is posting the record properly and at the time each change is made.

There should always be some system of recording the receipt of daily reports at the office. This is sometimes effected by having a tabular list of all the reports that should be received, and by placing a check mark opposite the name of each report (or each foreman or individual making the report) under the day of the month to which the report relates. A glance at such a tabulation shows whether any report is missing.

If it is the practice to plot or chart the returns shown by each report daily, then no further check may be needed to show that the report has been received.

One of the advantages gained by divorcing cost keeping from bookkeeping is the check thus obtainable on both. The aggregate weekly payroll shown by the timekeeper's report should check fairly well—not necessarily with great precision—with the aggregate payroll deduced from the foreman's reports. Incidentally this check makes it more difficult for a timekeeper to "pad the payroll," that is to enter fictitious names upon the payroll or to credit a man with more time than he is entitled to. Many a contractor has been robbed in this manner.

If the distribution of costs shown on the books corresponds with the distribution derived from the daily report cards, a fairly close check is obtainable.

It is generally wise to have accounts for each of the main items of materials and supplies, such as lumber, cement, coal, explosives, etc. Then the total consumption of coal, for example, as deduced from the foremen's daily cost reports, should check fairly well with the amount purchased, as recorded by the bookkeeper. Likewise the bookkeeper may divide the payroll into certain general classes of labor and assign an account for each class, which should check with the cost records turned in by the foremen. But, in our opinion, it is a serious mistake to encumber the bookkeeper with a multiplicity of accounts intended either to show detailed costs or to check the various details of cost deduced from the daily cost reports.

Cost Charts.—For showing relative performance or relative unit costs, no method is so satisfactory as a diagram or chart. A glance at the unit cost line plotted on a chart shows the manager whether there is cause for congratulation or alarm. The up and down waves of a cost line are far more impressive than columns of figures ever are.

A chart of daily performance has the incidental advantage of affording an automatic check on whether all the daily cost reports have been turned in or not, for without the reports the lines on the chart cannot be plotted.

Progress Charts.—It is generally desirable to record graphically

the progress of each particular class of work on a contract. This is best done by means of a progress chart similar to that shown in Fig. 11.

This chart relates to excavation. The first column is a percentage column. The second column gives the length of the excavation (trench, ditch, or the like). The third column gives the number

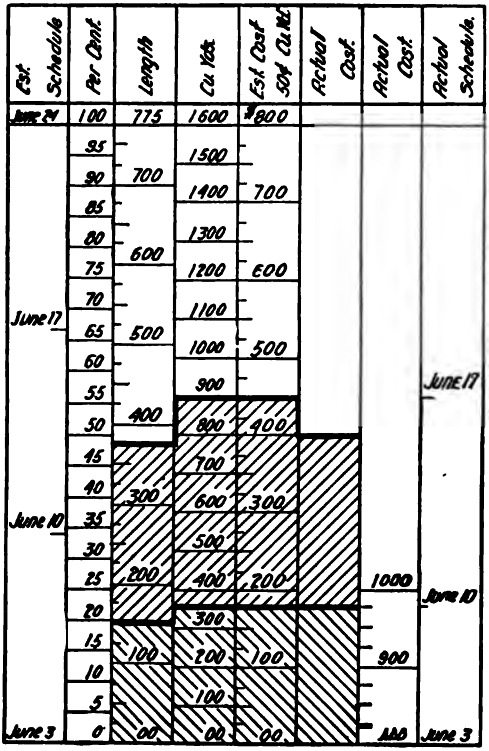


Fig. 11. Progress Chart.

of cubic yards. The fourth column gives the estimated cost. The fifth column gives the actual cost; a sixth column of actual cost is provided in case it overruns the estimated cost. The total length of the excavation to be done is 775 ft., which is written opposite the 100%. Then the length column is divided into 7¾ parts, each representing 100 ft., or a "station."

The total yardage in this length of 775 ft. is 1,600 cu. yds., which

is also written opposite the 100%. Then this yardage column is divided into 16 parts, each representing 100 cu. yds. The work has been estimated to cost 50 cts. per cu. yd., therefore the total cost of the 1,600 cu. yds. should be $800, which is written opposite the 100%; and the estimated cost column is divided into 8 parts, each representing $100.

This work on section of excavation is scheduled to begin June 3, as indicated in the space to the left of the per cent column and at the bottom; and it is scheduled to be finished in three weeks, as indicated.

The work is begun on schedule time, June 3, as indicated by the entry to the right of the last column, and at the end of the first week (beginning of the next), June 10, the progress and cost are shown by the hatched portion below the heavy black line. It will be seen that the excavation has been completed to station 1 + 50 (= 150 ft.), as shown in the second column; and that 350 cu. yds. have been excavated, as shown in the third column. The estimated cost of the 350 cu. yds. is $175, as shown in the fourth column. The actual cost has been proved to be the same as the estimated cost, or $175, as shown in the fifth column. The yardage completed up to June 10 is 22% of the total, as seen by comparing the first, or percentage, column with the third, or yardage, column; whereas, to have lived up to the estimated schedule, 33% of the yardage should have been excavated by June 10.

The performance of the next week is similarly shown by the heavy black line opposite June 17, which shows that 47.5 ft. of length (reaching therefore to Sta. 4 + 75) and 900 cu. yds. have been completed. The total actual cost is now $400, as compared with an estimated cost of $450, showing that the work is being handled satisfactorily.

If the chart is plotted on tracing cloth, blue prints are readily made. Instead of cross-hatching the performance area of each week, paints of different tints may be used.

On jobs of long duration, a similar chart showing progress by months is usually desirable, in addition to a weekly progress chart. Then it is often desirable to paint the area on the monthly progress chart, using colors of paints to designate the different months.

Methods of Payment in Proportion to Performance.—The fundamental law of management involves that payment for work done shall be proportionate to performance—that is, an increased number of units of work done by a man shall result in his receiving increased pay. The ordinary wage system is based upon this law, but only in a very crude manner, since it throws men into large groups or classes, individuals of which receive the same pay, or practically so.

We shall now consider some of the various methods that aim to recompense a workman in proportion to his performance.

Profit Sharing.—According to the method of profit sharing, each individual receives not only his wage but a pro rata of any profits that arise from the business. Either quarterly, semi-annually, or

annually, the profits of the business are estimated, and a certain percentage of these profits is distributed to the workmen and their managers. Often this distribution of profits is confined to the managers only.

While this is an improvement over the wage system, it violates the eighth law of management—namely, the law of prompt reward. The imagination of the ordinary workman is not enough to maintain his interest in his work at the high pitch necessary to enable him to do his very best. Moreover, any community interest in a commercial enterprise lacks sufficient stimulus. It requires a more direct, personal interest in the outcome to arouse a man to action.

Profit sharing, whether by the payment of profits direct, or in the form of dividends on stock held by the workman, is, at best, only a moderate step in advance of the ordinary wage system so far as the average workman is concerned.

Piece Rate System.—According to the piece rate system, each workman is paid a certain stipulated amount per unit of work done by him. If all managers were fair in their dealings with workmen, and if all workmen were reasonable, the piece rate system would be almost ideal as a method of paying men wherever the work is of a character that admits of measuring individual performance. Due to hoggishness on the part of managers and unreasonableness on tne part of workmen, the piece rate system usually fails to accomplish the desired end.

Having established a piece rate of, say, 10 cts. per cu. yd. for shoveling earth into wagons, on the assumption that 15 cu. yds. per day per man is a fair output, it requires more than ordinary foresight and liberality not to cut the rate when laborers begin to load 25 cu. yds. a day. The typical contractor will then begin to reason about as follows: "These men have been soldiering on me in the past. I always thought so; now I know it. Well, now that I do know it, and they know I know it, they will have to work at this rate hereafter or get out. What's more, I am not going to be gouged out of an extra dollar a day, either. If they make 25 cts. extra a day, it's more than they ever got before, and it's all they are entitled to, so we will just drop that 10-ct. rate down to 7 cts. That will satisfy them." But the trouble is that it doesn't. The men immediately become angry, and rightly so. If they do not quit entirely, they lose all further ambition and desire to increase their output, knowing full well that the piece rate will be so cut as to enable them to earn only a slight advance over their original day's wages.

This experience has been so general that nearly all labor unions have put a ban on the piece-rate system. Bear in mind, however, that the piece-rate system is not inherently at fault, and that it is used with great success in many places where the management has been liberal and far-sighted.

On piece-rate work that involves the use of machinery, it is manifest that any improvement in the machinery which enables the men to turn out more units daily, should be accompanied by some reduction in the piece rate. Workmen, however, are usually unrea-

sonable and oppose any reduction in the rate. This unreasonableness disgusts the manager as much as a manager's hoggishness disgusts the workmen. If the manager goes to the expense of buying and operating improved machinery, he is entitled to his share of the increased profit, but the workman is not quick to see things in that light.

Obviously, any piece-rate system is productive of more or less friction between managers and men, yet no system is free from some friction. Probably the chief function of the labor unions of the future will be to protect workmen in agreements with managers, and to be parties in arriving at what those agreements shall be.

The Bonus System.—This system involves paying each workman a daily wage plus a piece rate on each unit in excess of a stipulated minimum. This piece rate on excess product is called a bonus. For example, a laborer receives $1.50 a day for shoveling earth, and on each cubic yard in excess of 15 cu. yds. shoveled per day he receives a bonus of 7 cts. If he shovels 25 cu. yds., he receives $\$1.50 + (0.07 \times 10) = \$2.20$.

The bonus system is really a piece-rate system with a guarantee of a certain minimum wage. Slight though this difference from the piece-rate system is, it is generally viewed with more favor by workmen.

The Differential Piece Rate System.—The principle of this system is to pay a certain piece rate up to a certain output per man, and a higher rate (but still a piece rate) above that output. Applied to drilling, for example, the drill runner would be paid, say, 6 cts. a foot up to a performance of 50 ft. per day, and 8 cts. a foot for every foot above 50. The helper might still be paid $2 a day straight, but it is wise always to give him also a contingent interest in the result of his work.

The Differential Bonus.—This is based on the same principle as the differential piece rate while guaranteeing to a man a fixed minimum of wages. We have applied it in drilling work, offering the men 2 cts. per foot drilled for every foot above 70, and 3 cts. for every foot above 80 per day, while at the same time paying them their regular rate of wages.

Task Work With a Bonus.—Mr. H. L. Gantt, one of Taylor's pupils, invented a system of differential payment known as "Task Work with a Bonus," which has been very successful in practice and has great flexibility of application under varying conditions. The workman under this system is paid his regular day's wages in any event and a certain lump bonus if he succeeds in accomplishing the standard task. The amount of this bonus is usually about one-third of his regular wages. Mr. Taylor says that this system is especially useful during the difficult and delicate period of transition from the slow pace of ordinary day work to the high speed which is the leading characteristic of good management. During this period of transition in the past, a time was always reached when a sudden leap was taken from improved day work to some form of piece work; and in making this jump many good

men inevitably fell and were lost from the procession. Mr. Gantt's system bridges over this difficult stretch and enables the workman to go smoothly and with gradually accelerating speed from the slower pace of improved day work to the high speed of the new system.

The Premium Plan.—This is the term used by Mr. F. A. Halsey to describe what Mr. Taylor calls the Towne-Halsey system. It is based on the proposition of paying a bonus for achieving an estimated performance, the means to be employed and the methods being left to the ingenuity and initiative of the men, rather than to the management.

Principles Governing the Fixing of a Piece Rate or Bonus.—We are probably well within limits when we say that the average workman engaged on construction work under the wage system is capable of increasing his output 70% if given sufficient incentive to do so, and this without the least physical injury to himself. When it is desired to ascertain how much work men are capable of doing, one of the best plans is to conduct a contest between two or more men, or two or more groups of men, a substantial prize being offered for the best performance. Such a contest should usually extend over several consecutive days, so that it will not be a mere sprint, but a fair endurance test.

If a competitive contest to disclose the workmen's abilities is not practicable, the authors assume that the output probably can be increased 60 to 70% over the output under the wage system, wherever the output depends mainly on the skill and strength of the workmen. In drilling rock, for example, if the average output of each drill is 60 lin. ft. under the wage system, then, in all likelihood, it can be increased to nearly 100 ft. under a bonus system. The driller who receives $3.00 a day under the wage system is really earning 5 cts. for each of the 60 lin. ft. If it is planned that he shall increase his income 50%, he will receive $4.50 for the assumed 100 lin. ft. of hole. Hence his piece rate would be 4½ cts. a foot, or his bonus would be $1.50 on 40 lin. ft. (60 lin. ft. being taken as the standard minimum performance), which is equivalent to a bonus of 3¾ cts. per lin. ft. on every foot in excess of 60 ft. to be added to a daily wage of $3.00. At first sight it seems that the contractor gains only 1¼ cts. per lin. ft. for the 40 lin. ft. on which a bonus is paid, or only ½ ct. per lin. ft. on the entire 100 ft. The fact is that the contractor gains much more, not even considering the wages of the driller's helper, for the daily plant charges on the drill remain almost constant, regardless of the output. If fuel, fireman, interest, repairs, depreciation, foreman, etc., are $4.00 per day per drill, these fixed charges amount to 6.66 cts. per lin. ft. of hole when the output is only 60 lin. ft. a day, as compared with 4 cts. per lin. ft. when the output is 100 ft., or a saving of 2.66 cts. per lin. ft. Wherever a plant of any considerable value is used, it is clear that it would be profitable to double the pay of the workmen if they could double the output of the plant, for the unit saving in plant charges alone would amount to

a handsome profit. This is upon the assumption that the fuel bill remains practically unchanged by the increased output, and it seldom is materially affected by increased output on contract work.

Benefits of the Bonus System.*—Strife develops the best that is in a man, whether it be strength of muscle or the power of the mysterious marrow of the skull.

The evolution of all species and genera, up to man himself, is based upon this law, yet there are millions of misguided men who are striving to abolish strife. They show more pity for the second best in the race than praise for the first. They seem not to see that in the industrial race even the loser wins, and that there is no such thing as being beaten out of "place." A part of the purse goes to everyone that enters.

But there are many kinds of races, and many entries in each. The most popular race, judged by the number of entries, is the slow race. In it you will find men of all classes—clerks, farmers, brick masons, draftsmen, iron workers, and, indeed, the great majority of men working for wages. The one who can make the job last the longest wins. He wears the blue ribbon, and is proud of himself in a sneaking sort of fashion. But the part of the purse for the winner in this race is no greater than for the loser. There is merely the blue ribbon for the prize winners.

Entered in the running race are all men working in competitive businesses. Here are the merchants, manufacturers, contractors, etc.

Then there is the trotting race, not so swift nor so trying, but a contest well worth watching. Here is where careful training counts. This is the race for men educated in the profession of law, medicine, architecture and engineering—each in his class.

What marks the distinction between these three different kinds of runners? Why does the wageworker go slow? Why is the professional man more energetic? Why is the business man the personification of energy? The answer is found in the relative freedom of competition, and the relative size of the prizes to be won.

The wageworker has, from time immemorial, striven to limit competition. In China and India he has succeeded to perfection. There he has developed a system called "caste," which is but a perfected form of our English and American "apprentice system." In India a man belonging to a certain "caste" will swing a wet blanket over you all night to keep you cool; but no amount of money would tempt him to black your shoes or go to the postoffice for your mail. He does not belong to the "caste" that does those things. Hence you must hire ten or a dozen servants if you expect to be served in all your wants. "It makes work," don't you see? It has the slow runner beaten to a standstill.

How can wageworkers be rescued from their own follies, not merely in India, but in America? How can they be induced to enter races for the swift, where the swiftest wins most, but all win more? There is but one, just one, way to bring this end about, and

***Engineering-Contracting*, Feb. 6, 1907.

that is to extend the contract system to individuals and to groups of individuals. When men are paid directly in proportion to what they do, then they DO.

This is the true secret of the economy of performing public work by contract instead of by day labor. And it can be carried a step farther. The contractor can make his men sub-contractors, if he will exercise a little ingenuity and patience in working out a plan for paying them by the piece.

There are many men who are not gifted with the ability to manage workmen where the plain wage system is in use, but who would succeed admirably in getting a big output from men under a bonus or a "piece-work" system. It can be done not only in the field and factory, but in the office, not only where laborers are hired, but where engineers are hired. It is being done with great success in surveying and drafting—two classes of work where the difficulties of applying a bonus or contract system are very great.

When you are told that the bonus system cannot be applied to some particular class of work, because of its unusual nature, place little reliance in the dictum but put your brains at work. Let others enter the race ridden by the jockey Impossible, if they will, but that jockey never bestrode a winner since time began.

Time Cards and Time Books.—Through any stationery store time books can be bought that are ruled and lettered to suit most classes of contract work. The timekeeper enters the name of each man and assigns him a number in the book. On large jobs it is wise also to provide a brass check that can be pinned to the clothing of each workman, so that his number is visible at a glance. The home addresses of common laborers are seldom entered in the time books, but it is desirable always to record home addresses of all men, and particularly the permanent addresses of skilled workmen and foremen. A few postal cards will thus enable one quickly to gather together a gang of skilled men for a new job. It is wise also to have a directory book for entering the names of good foremen, whether they be men that you have employed or not; and a few brief remarks concerning each man's fitness for particular classes of work shold be entered. This assists also in identifying men whose names have slipped the memory.

Time books are very often ruled so that the job the men are working on cannot be entered opposite each man's name. It is necessary then to reserve separate pages for each job. Then if a man does several different kinds of work on one job, as many different lines are reserved under his name so that the hours and fractions spent by him on each kind of work can be recorded. In that case the foreman is provided with a time book from which the timekeeper makes abstracts when he goes the rounds.

In order to avoid disputes on pay day, I devised the form of card shown in Fig. 12. Each workman is provided with one of these cards which he keeps until pay day. This card was devised for work on which pay day came every second week. The rate of wages is punched with a conductor's punch, likewise the number of hours and the nearest half hour of each day. The timekeeper or

foreman punches every man's card at the end of the day, and at the same time enters the number of the man and his hours in the time book. If any dispute arises as to the number of hours worked

In accepting this card, I declare that I am a citizen of the United States.

NAME.................................... NO....................................

CONTRACT.................................... OCCUPATION....................................

Week Ending PAID. DISCHARGED. Week Ending

Sun.	Mon.	Tues.	Wed.	Thur.	Fri.	Sat.
½	½	½	½	½	½	½
1	1	1	1	1	1	1
2	2	2	2	2	2	2
3	3	3	3	3	3	3
4	4	4	4	4	4	4
5	5	5	5	5	5	5
6	6	6	6	6	6	6
7	7	7	7	7	7	7
8	8	8	8	8	8	8
9	9	9	9	9	9	9
10	10	10	10	10	10	10

TIME CARD.

G—— & G——
Engineering Contractors.

Rate per Hour.

5	7½	10	12½	15½
16	20	37½	30	35

Sun.	Mon.	Tues.	Wed.	Thur.	Fri.	Sat.
½	½	½	½	½	½	½
1	1	1	1	1	1	1
2	2	2	2	2	2	2
3	3	3	3	3	3	3
4	4	4	4	4	4	4
5	5	5	5	5	5	5
6	6	6	6	6	6	6
7	7	7	7	7	7	7
8	8	8	8	8	8	8
9	9	9	9	9	9	9
10	10	10	10	10	10	10

Fig. 12. Time Card.

the dispute must be settled then and there, for on pay day no claims for extra time will be listened to. This does away entirely with pay day disputes, which is a very satisfactory feature. The

card also serves to check the timekeeper's records. Moreover, it makes "padding" of payrolls more difficult, and facilitates detective work if "padding" is suspected. The card also serves as a discharge slip; for, when a man is discharged, the foreman punches the hours that he has worked and he also punches a hole through the word "discharged." When the man presents the card at the office he is paid; the card is kept as a voucher, and a hole is punched through the word "paid."

Recording Work by Minute Hand Observations.—It has often been said that short time observations prove nothing as to the efficiency of men or machines. This statement has been exceedingly misleading to those who have accepted it as a self-evident truth. When a short time observation does not include the common delays incident to shifting tools, to breakdowns, and the like, it may lead to a serious underestimate of the cost of work. On the other hand, when the so-called short time observation is made long enough to include the time spent in necessary rests, in moving machines, in repairs to plant, and the like, exceedingly valuable results may be obtained. When it is desired to find whether men are lazy, whether a foreman knows his business, whether the method of doing the work can be bettered, or whether the tool or machine is susceptible of improvement, there is no method to be compared with the method of timing work with the minute hand of a watch. Moreover, where it is desired to discover the effect on cost of varying the length of haul, of varying the kind of rock drilled, and the like, timing with the minute hand is the only satisfactory way of arriving at definite conclusions.

If a stop-watch is not available, an ordinary watch with a second hand will serve, and in many classes of work even the second hand can be dispensed with. An example will now be given to illustrate the method and value of a short time observation.

Before beginning the record, set the minute hand so that it points an even minute when the second hand points at 60. Suppose it is desired to time the drilling of a hole in a seamy mica-schist, using a steam drill mounted on a tripod. At 9:37 a. m. the driller is set up and ready to begin drilling a hole and exactly 30 seconds later he turns on the steam; then we begin our record:

9:37:30	Start.
9:49:20	Down.
9:51:20	Start.
10:00:40	Down.
10:03:40	Start.
10:09:40	Down.
10:13:00	Start.
10:14:40	Bit sticks.
10:24:40	After hammering the drill repeatedly, the driller is directed to break up some cast iron and throw it into the drill hole.
10:32:30	Drilling begins again.
10:45:00	Hole finished.
11:15:10	New hole started.

It will be seen that drilling started at 9:37:30, and that at 9:49:20 the full length of the feed screw was out, and that to drill farther a new bit had to be inserted. At 9:51:20 the new bit was in and drilling began again, after a delay of 2 mins. in changing bits. At 10:00:40 the second bit was down. Each successive bit, it should be stated, is usually 2 ft. longer than its predecessor. At 10:14:40 the bit sticks in the hole due to having run into a pocket of rotten rock. The observer might readily have predicted this sticking by noting the increased rapidity of penetration; for it took nearly 12 mins. to drill the first 2 ft. of the hole, and only 6 mins. to drill the 2 ft. just prior to the sticking. After wasting 10 mins. abusing the drill the driller finally removed the bit (at the direction of the observer), broke up a piece of cast-iron pipe into hazel nut sizes, and threw two handfuls of the iron into the bottom of the hole. Drilling was resumed at 10:32:30, and the last 2 ft. were completed at 10:45:00. At 11:15:10 the driller started another hole, having spent more than 30 mins. shifting the tripod and drill.

What do we learn from this observation? First that the driller was slow in changing bits; second, that he was very slow in shifting his tripod; third, that the driller was ignorant; fourth, that the foreman was equally so; fifth, that fragments of cast iron completely overcome sticking of bits in this rock.

We know that the driller was slow, because other similar observations have proved it possible to change short bits in much less time than 3 mins., and, since the driller has an easy time of it while turning the crank, he can work rapidly without exhausting himself when it comes to changing bits or shifting the machine. We know that both driller and foreman were ignorant, for broken iron should have been provided ready to use in case of sticking of the bit. We conclude that it will pay to assign a man to measure up the footage of hole drilled by each driller every day, and to offer each driller a bonus for every foot of hole drilled in excess of a stipulated minimum.

The foregoing is a record of fact and not of theory. On a large contract job I secured an increase of 45% in the daily footage of each drill by taking just such observations as the above.

I have found it of great advantage to time in detail the work of cableways, derricks, steam shovels, concrete mixers, dinkey locomotives, pile drivers and other machines used on contract work. Even the output of men working with hand tools can be profitably studied in the same way. The number of shovelfuls of earth may be timed under different conditions, with a view to ascertaining the effect of changed conditions, and the effect of using larger shovels. However, the greatest gains from minute-hand timing occur when it is applied to machines operated by power rather than to hand work.

It is desirable in nearly all cases not to let the workmen know that they are being timed. When men are working in the open air, an observer can often use the telescope of a transit or a pair of field glasses to good advantage. In shop work, or underground, where the observer must be near the men, a convenient way of timing any detail of work is by counting. One can soon learn to

count with regularity, and thus dispense with a second or minute hand. Other methods of ascertaining the time of doing work without being observed will occur to anyone who gives thought to the matter.

SECTION II.

EARTH EXCAVATION.

Magnitude of the Subject.—Probably no kind of engineering work involves as many varying factors as earth excavation. Not only is there a wide range of classes of earths but the tools for excavation are almost as varied as the conditions encountered. Taken as a whole, accurate estimating of the cost of earthwork is probably more difficult than estimating the cost of any other item of construction discussed in this book. Having already written one book on earthwork, and having another and much larger treatise in preparation, I shall give in this section only the very briefest summary of some of the commoner methods of earth excavation and cost.

In other sections of this book will be found supplementary data on earthwork, for which consult the index under "Excavation, Earth."

Earth Measurement.—Earthwork is paid for by the cubic yard, and is usually measured "in place," that is, in the natural bank or pit before it has been loosened. The price paid usually includes the excavating, hauling and placing the earth in the embankment, and no extra price is paid for making the embankment—in other words, the earth is paid for but once. Occasionally, in dike work, in building reservoir embankments, and wherever it is very difficult to measure the earth in place, it is specified that the earth shall be measured in the consolidated embankment. However, unless otherwise stated, all costs given in this book refer to measurements of earth in place.

Many specifications for railroad work contain an "overhaul clause," which provides that for all earth hauled more than a certain specified limit, the contractor shall be paid a certain amount per cubic yard, usually 1 ct. per cu. yd. per 100 ft. overhaul. The specified limit of "free haul" is sometimes 1,000 ft., sometimes 500 ft. Even in case of an overhaul, no additional payment is made for building the embankment, but only for the overhaul.

Earth Shrinkage.—Earth when first loosened and shoveled into a wagon swells, that is, it occupies more space than it did "in place"; but, when placed in an embankment and rolled or pounded down, it shrinks, and this shrinkage is often so great that the earth occupies less space in the embankment than it did "in place." The following is a summary, based upon data of actual tests given in my book on earthwork:

1. Taking extreme cases, earth swells when first loosened with

a shovel, so that after loosening it occupies 1 1/7 to 1½ times as much space as it did before loosening; in other words, loose earth is 14% to 50% more bulky than natural bank earth.

2. As an average, we may say that clean sand and gravel swell 1/7, or 14% to 15%; loam, loamy sand or gravel swell 1/5, or 20%; dense clay, and dense mixtures of gravel and clay, ⅓ to ½, or 33% to 50%, ordinarily about 35%; while unusually dense gravel and clay banks swell 50%.

3. Loose earth is compacted by several means; (a) the puddling action of water, (b) the pounding of hoofs and wheels, (c) the jarring and compressive action of rolling artificially.

4. If the puddling action of rains is the only factor, a loose mass of earth will shrink slowly back to its original volume, but an embankment of loose earth will at the end of a year be still about 1/12, or 8%, greater than the cut it came from.

5. If the embankment is made with small one-horse carts, or wheel scrapers, at the end of the work it will occupy 5 to 10% less space than the cut from which the earth was taken, and in subsequent years will shrink about 2% more, often less than 2%.

6. If the embankment is made with wagons or dump cars, and made rapidly in dry weather without water, it will shrink about 8% to 10% in the year following the completion of the work, and very little in subsequent years.

7. The height of the embankment appears to have little effect on its subsequent shrinkage.

8. By the proper mixing of clay or loam and gravel, followed by sprinkling and rolling in thin layers, a bank can be made weighing 1¾ times as much as loose earth, or 133 lbs. per cu. ft.

9. The bottoms of certain rivers, banks of cemented gravel, and hardpan, are more than ordinarily dense, and will occupy more space in the fill than in the cut unless rolled.

Kinds of Earth.—Earth may be divided into three classes as regards difficulty of excavation: (1) Easy earth; (2) average earth; and (3) tough earth. To the first class belong loam, sand, and ordinary gravel, which require little or no picking to loosen ready for shoveling. To the second class belong sands and gravels impregnated with an amount of clay or loam that binds the particles together, making it necessary to use a pick or a plow drawn by two horses to loosen the earth before shoveling. To the third class belong the compact clays, the hardened crusts of old roads, and all earths so hard that one team of horses can pull a plow through the earth only with greatest difficulty, but that two teams of horses on one plow can loosen with comparative ease.

This third class of earth passes by insensible degrees into what is called "hardpan." Hardpan commonly means a very compact clay, or mixture of gravel or boulders with clay. Soft shales that can be plowed with a rooter plow are sometimes called hardpan. There are also certain gravels cemented with an iron oxide (iron rust) which are called hardpan.

There are many local names applied to different kinds of earth.

"Adobe" is a name much used in Texas, Arizona, California and and neighboring states to denote any clay of which mud bricks, or adobes, might be made. "Gumbo" is a word used in the Mississippi Valley to denote a black loam containing so much clay as to be exceedingly sticky when wet. "Marl" is, strictly speaking, a mixture of clay and pulverized limestone, but the term is often applied to clay soils containing only 1% to 2% of limestone dust, as, for example, the greensand marls of New Jersey. There are many local deposits of disintegrated minerals, which, when soapy in texture, are often called marl. In some cases these deposits are so greasy that, when saturated with water, slides and cave-ins occur when an attempt is made to excavate them.

Quicksand is a term applied to any sand, or sandy material, which flows like molasses when the sand is saturated with water.

In this book the rules for estimating costs, unless otherwise stated, relate to "average earth," as above defined.

Definitions of Haul and Lead.—"Lead" is a term used to denote the horizontal distance in a straight line from the center of mass of the pit to the center of mass of the dump. The pit, in this case, refers to the volume of earth to be excavated, and the dump refers to the embankment. The "lead" does not include the distance actually traveled, including turnouts, etc., from pit to dump; this actual distance traveled by the cars or wagons is called the "haul." The "haul" is then half the distance traveled by a car or wagon in making a round trip.

Work of Teams.—A "team," as used in this book, means a pair of horses *and* their driver. Even where the word driver is omitted in speaking of the cost of team work, the wages of the driver are always included under the word "team."

A good average team is capable of traveling 20 miles in 10 hrs., going 10 miles loaded and returning 10 miles empty, over fairly hard earth roads. If the team is traveling constantly over soft ground, 15 miles is a good day's work. On the other hand, if the team is traveling over good gravel or macadam roads, or paved streets, it is possible to average 25 miles per 10-hr. day. These rates include the occasional stops made for rests, etc., and include the climbing of an occasional hill.

When traveling at the rate of 2½ miles an hour, which is the ordinary walking gait of horses, the distance covered in 1 min. is 220 ft. Over good hard roads a team may trot with an empty wagon at the rate of 5 miles per hr., and thus make up for delays in loading and unloading, so as to cover the full 20 miles of daily work; but over soft ground a team should not trot.

The loads that a team can haul (in addition to the weight of the wagon) over different kinds of roads are as follows:

	Short tons.	Earth, cu. yds.
Very poor earth road..................	1.0	0.8
Poor earth road......................	1.25	1.0
Good hard earth road..................	2.0	1.6
Good clean macadam road............	3.0	2.4

It is not possible to haul much greater loads over an asphalt or

brick pavement than over a first-class, clean macadam. On all the kinds of roads to which the above averages apply, there may be occasional steep grades to ascend, and occasional bad spots to pass over.

The pulling power of a horse averages about one-tenth of his weight when exerted steadily for 10 hrs.; that is, a 1,200-lb. horse will exert an average pull of 120 lbs. on the traces. But for a short space of time the horse can exert a pull (if he has a good foothold) equal to about four-tenths his weight, that is, four times his average all-day pull. This I have tested with teams, not only in ascending steep grades but in lifting the hammer of a horse-operated pile driver.

Where teams are traveling long distances, it is customary to have two wagons keep together, so that one team can help the other up a steep hill by acting as a "snatch team." A "snatch team," or helping team, may often be kept busy to advantage in pulling heavily loaded teams out of a pit, or onto a soft embankment, or up a steep grade. Three-horse snatch teams are frequently used. A small hoisting engine may replace a snatch team to advantage in many places. By laying channel irons for rails up a steep hill, and having a hoisting engine at the top, very heavy loads can be assisted over bad roads. In this case, a boy mounted on a pony can drag the hoisting rope back to the foot of the hill ready for the next team. Plank roads can often be built to advantage for short distances up steep grades, or over bad spots.

In the far West it is customary for three or more teams to be hitched to a train of two or more wagons; and, when a steep hill is to be ascended, to haul one wagon up at a time. This saves wages of drivers.

In the last section of this book, Miscellaneous Costs, will be found further suggestions on hauling with teams, also costs of feeding and maintaining teams. Consult the index under Hauling, Teams.

Cost of Plowing.—A team on a plow will loosen 500 cu. yds. of loam, or 350 cu. yds. of loamy gravel, or 250 cu. yds. of fairly tough clay, per 10-hr. day. For "average earth," therefore assume 350 cu. yds. per day loosened by a team and driver and one man holding plow. With wages at $3.50 for team and driver, and $1.50 for laborer, the cost of plowing average earth is 1½ cts. per cu. yd.

In plowing very tough material with a pick-pointed plow, four horses and three men, estimate 180 cu. yds. plowed per day at a cost of 5 cts. per cu. yd.

For tough material there has recently been developed a "gang plow" of remarkable efficiency. It consists of a framework mounted on four small wheels, and equipped with five rooters or plows. These plows can be quickly set, by means of levers, to plow or cut to any desired depth. From 6 to 12 horses, or a traction engine, pull the gang plow, and it cuts five furrows at once. This gang plow is made by the Petrolithic Pavement Co., Los Angeles, Calif.

Cost of Picking and Shoveling.—When wages are $1.50 per 10-hr.

day, the cost of loosening earth with a pick (instead of a plow) ranges from 1 ct. per cu. yd. for very easy earth, to 11 cts. per cu. yd. for very stiff clay or cemented gravel; for "average earth" the cost of picking is about 4 cts. per cu. yd.

The cost of loosening with a pick and shoveling into wagons is as follows, wages being 15 cts. per hr.:

	Per cu. yd.
Easy earth, light sand or loam................	12 cts.
Average earth	15 cts.
Tough clay	20 cts.
Hardpan	40 cts.

The amount of earth that a man can load with a shovel varies with the character of the earth, the way it has been loosened, the size and shape of the shovel, etc. If a man is shoveling earth from the face of a cut that has been undermined and broken down with picks, he can readily load 18 cu. yds. per 10-hr. day, after the earth has been loosened. If he is shoveling plowed earth, where he must use more force in driving the shovel into the soil, he will easily load 14 cu. yds. of average earth in 10 hrs. If he is shoveling loose earth off boards upon which it has been dumped, he can load 25 cu. yds. in 10 hrs., but it is not wise to count on more than 20 cu. yds. even under good foremanship.

For data on the cost of trenching, the reader is referred to the sections on Sewers and on Water-works. Consult the index under "Excavating, Trenches."

Cost of Trimming, Rolling, Etc.—After earth has been dumped from carts or wagons, a man will spread in 6-in. layers by hand 75 cu. yds. in 10 hrs., at a cost of 2 cts. per cu. yd. A leveling scraper, or road machine, will spread large quantities of earth for ½ ct. to ¾ ct. per cu. yd. With a leveling scraper operated by a team and driver and a helper, I have had 500 cu. yds. spread per day. A road machine, operated by 6 horses and 2 men, will spread 900 cu. yds. in 10 hrs. in 6-in. layers, earth having been dumped from patent dump-wagons.

A man can thoroughly tamp 25 cu. yds., in 6-in. layers, per 10-hr. day at 6 cts. per cu. yd. Embankments can be consolidated with horse-drawn rollers for ½ to 1 ct. per cu. yd., wages of a team being $3.50 a day. I have one record of 4 cts. per cu. yd. (at the above wages), for rolling a reservoir embankment, but the work was not well handled.

The cost of sprinkling embankments, if specified, is difficult to estimate because of the vagueness of specifications. However, more than 8 cu. ft. of water per cu. yd. of earth, is seldom required.

On a large embankment three sprinkling carts, each drawn by three teams, with one driver, sprinkled 1,000 cu. yds. of earth per day of 10 hrs., with short haul. Such carts each held 150 cu. ft. of water weighing 4½ tons, which is an exceedingly large capacity. A sprinkler of this size can be loaded from a tank in 15 mins., and emptied in the same length of time. Knowing the length of haul and speed of team the cost of sprinkling is readily determined. In

the case just given the cost was 2¼ cts. per cu. yd. of earth for sprinkling and about 5 cu. ft. of water per cu. yd. were used.

From several careful observations the writer has found that a gang of men under a good foreman will each trim the sod and humps off the hard surface of a cut to the depth of 1 or 1½ ins. at the rate of 200 sq. ft. or 22 sq. yds. per hour, at a cost of 2/5 ct. per sq. yd.; and where there was no sod to remove, the soil being sandy loam, the cost was one-half as much or ⅕ ct. per sq. yd. Massachusetts contractors bid almost uniformly 2½ cts. a sq. yd. for "surfacing" (wages 17 cts. per hour), which includes rolling the finished surface with steam roller.

A roadway, including ditches, 36 ft. wide and a mile long, has 21,000 sq. yds. of surface, which at ⅔ ct. is $140, actual cost of trimming. If the total excavation in a mile is 3,500 cu. yds. (which is about the average in N. Y. State), the cost of trimming, distributed over this 3,500 cu. yds., is 4 cts. per cu. yd. of excavation, a cost much greater than a mere guess would lead one to suppose.

I have directed the scraping of a light growth of weeds and grass off the 4-ft. shoulder of a road by going once over it with a leveling scraper, at a rate of 200 sq. yds. per hour, or ten times faster than a man with a mattock would have done it; making the actual cost about ¼ ct. per sq. yd. where the team, driver and helpers' wages were 50 cts. per hour.

Cost of Wheelbarrow Work.—A man wheeling a barrow over run-plank can not be counted on to travel more than 15 miles per 10-hr. day. If the runway is level a load of 300 lbs. or more may be wheeled in a barrow, but it is not safe to count upon more than 250 lbs., or 1/10 cu. yd. of earth. This is for good level runways, but, as most wheelbarrow work involves ascending steep grades, estimate 1/14 to 1/15 cu. yd. per barrow load. With wages at 15 cts. per hr., the cost of wheeling earth in barrows is, therefore, 5 cts. per cu. yd., per 100 ft. of haul, the haul being the distance from pit to dump. If the runways were level, and the men worked hard, the cost might be reduced to 3 cts. per cu. yd. per 100 ft. of haul.

The cost of picking and loading has already been given, and may be assumed to be 15 cts. per cu. yd. A wheelbarrow is dumped in about ¼ min., which is equivalent to a loss of nearly 4 mins. per cu. yd., where 15 barrow loads make a yard; and this is equivalent to 1 ct. per cu. yd. for dumping the barrows. The time lost in changing barrows, etc., may easily add another 1 ct. per cu. yd. The rule for estimating the cost of loosening, loading and hauling average earth in barrows is as follows when wages are 15 cts. per hr.:

Rule I.—To a fixed cost of 17 cts. per cu. yd., add 5 cts. per cu. yd. per 100 ft. haul, when steep ascents must be made, or 3½ cts. per 100 ft. when level.

Cost by One-Horse Carts.—Small two-wheeled carts drawn by one horse are often used on railway work. If the haul is level or slightly down hill and over a well compacted embankment, a horse

will pull 0.6 cu. yd. per load; but over poor earth roads it is not safe to count upon more than 0.4 cu. yd. per load, if there are any steep grades to ascend. On short hauls of 300 ft. or less, one driver can tend to two carts by leading one to the dump while the other is being loaded. A gang of 4 or 5 men should load a cart with 0.4 cu. yd. in 3 mins., and it takes about 1 min. to dump a cart, so that 4 mins. of cart time are "lost" every round trip. If the wages of a horse are $1 per 10-hr. day, and the wages of a driver are $1.50 a day, the wages of a cart and half a driver are $1.75 a day. The 4 mins. "lost time" is therefore equivalent to 3 cts. per cu. yd. The cost of picking and loading average earth is about 15 cts. per cu. yd., as previously given. A dumpman can easily dump a cart load a minute, where he has no spreading to do; but the material is seldom delivered fast enough. If we assume 150 cu. yds. delivered to him in carts in 10 hrs., the cost is 1 ct. per cu. yd. for dumpman's wages. Hence the total fixed cost may be assumed as 15 + 3 + 1 ct., or 19 cts. per cu. yd. If the cart load is 0.4 cu. yd., and wages are as above given, we have the following rule:

Rule II.—To a fixed cost of 19 *cts. per cu. yd. add* ¾ *ct. per cu. yd. per* 100 *ft. of haul.*

If the material is plowed, and is shoveled easily, the fixed cost may become 14 cts. per cu. yd. instead of 19 cts.

If the haul is long, one driver may still attend to two carts by taking them both together to the dump. There are occasions, however, when one driver attends to only one cart; in such cases the cost of hauling is 1 ct. per cu. yd. per 100 ft.

In cities, where the carts travel over hard earth or gravel roads, a cart carrying ⅔ cu. yd. may be used. The cost of hauling is, then, ½ ct. per cu. yd. per 100 ft. haul, wages of cart and driver being 25 cts. per hour.

Cost by Wagons.—There are three types of four-wheeled wagons commonly used by contractors: (1) The slat-bottom wagon; (2) the bottom-dump wagon; and (3) the end-dump wagon. Any farmer's wagon can be made into a slat-bottom wagon by removing the wagon box and replacing it with "slats" of 3 x 6-in. sticks for a bottom, and 2 x 12-in., or 2 x 16-in., planks for sides and ends. The bottom-dump, or "patent dump-wagon," has a bottom consisting of two doors that swing downward in dumping.

The end-dump wagon dumps backward like a two-wheeled cart. The best makes of this type of wagon are provided with a geared device by which the dump-man slides the wagon box bodily backward over the axle of the rear wheels until it tips and dumps its load.

The loads that are commonly hauled in a wagon by one team are given on page 121.

To reduce the lost time in loading wagons a common expedient is to provide extra wagons which are loaded while the teams are on the road to and from the dump. A team can be changed from an empty wagon to a loaded wagon in 1 to 1½ mins.

Three horses should be used on each wagon far oftener than they

are used on contract work, as nearly 50% more material can be hauled per load than with two horses. In the far West, one often sees two teams (four horses) hitched to a wagon, even on short haul work.

One man aided by the driver can dump a slat-bottom wagon holding 0.8 cu. yd. in 1½ mins., at a cost of 0.4 ct. per cu. yd. for the dumpman's time and 1 ct. per cu. yd. for lost time of team, wages being 15 cts. per hr. for dumpman, and 35 cts. per hr. for the team. It takes 3 mins. for these men to dump a large slat-bottom wagon holding 1½ cu. yds., where the driver removes the seat before dumping and replaces it afterward. So that in either case we see that the cost of dumping is about 1½ cts. per cu. yd. If a binder chain is wound around the wagon box to hold the slats close together so that no earth will spill through onto a street pavement, it takes 5 mins. to dump the wagon.

The time required to dump a drop-bottom wagon is practically nominal, and the driver dumps his own wagon.

It takes about 1 min. for the dumpman and driver to dump an end-dump wagon.

In loading wagons there are usually enough men provided in the pit to load 1 cu. yd. into a wagon in 4 or 5 mins. or less. This is equivalent to 2½ to 3 cts. per cu. yd. for lost team time in the pit, which, added to the lost team time at the dump, gives us about 4 cts. per cu. yd. where slat-bottom wagons are used. The cost of the dumpman's time will never be much less than ½ ct. per cu. yd.; and, if the material is not delivered rapidly, it may be much more.

The cost of excavating and loading has been given in previous pages. We assume this cost to average 13 cts. per cu. yd., where the earth is plowed, and add 5 cts. for lost team time and dumping, we have a fixed cost of 18 cts. per cu. yd. Then the cost of hauling will depend upon the size of the load, and, assuming wages of team at 35 cts. per hr., and speed of travel 2½ miles an hour while actually walking, we have the following rule:

Rule III.—To a fixed cost of 18 cts. per cu. yd., add ½ ct. per cu. yd. per 100 ft. haul when the wagon load is 1 cu. yd.

For other wagon loads use the following:

	Per cu. yd. per 100 ft.
Load being 0.8 cu. yd., add	0.66 ct.
Load being 1.0 cu. yd., add	0.53 ct.
Load being 1.6 cu. yd., add	0.33 ct.
Load being 2.0 cu. yds., add	0.26 ct.
Load being 2.4 cu. yds., add	0.22 ct.

In round numbers, therefore, for a load of 1 cu. yd. we must add ½ ct. per cu. yd. per 100 ft. haul, or 28 cts. per cu. yd. per mile haul, wages of team being 35 cts. per hr.

Cost by Drag Scrapers.—A drag scraper, or slip scraper, is a steel scoop, not mounted on wheels, for scooping up and transporting earth short distances, and is drawn by a team. The ordinary No 2 drag scraper weighs 100 lbs., and is listed in catalogues as holding 5 cu. ft. of earth. The actual average load, however, is about 1-9 to 1-7 cu. yd. place measure.

In working drag scrapers on short leads there are usually three

teams traveling in a circle or ellipse of 150 ft. circumference. One man loads the scrapers in the pit as they go by, and each driver dumps his own scraper. When the gang is working properly, the actual speed of the teams is 2½ miles an hour, or 220 ft. per min., while actually walking; and the "lost time" in loading and dumping is ⅓ to ½ min. per trip, or, say, 3½ mins. per cu. yd., which is equivalent to 2 cts. per cu. yd. for lost team time when team wages are 35 cts. per hr. The man loading can readily load 1,500 scrapers per day, or, say, 180 cu. yds., so that the cost of loading is about ¾ ct. per cu. yd. The cost of plowing (see page 122) will average 1½ cts. per cu. yd. As above stated, the teams travel in a circle, and, no matter how short the "lead," room must be allowed for turning and manoeuvering the teams; this room is approximately 50 ft. at each end of the haul, so that we have 100 ft. of extra travel, or nearly ½ min. of time for each trip, in addition to the "lead." This ½ min. adds another 2 cts. per cu. yd. Summing up, we have the following fixed cost, exclusive of foreman's wages:

	Per cu. yd.
Lost team time loading and dumping	2 cts.
Wages of man loading	¾ cts.
Plowing	1½ cts.
Extra travel of team in turning, etc.	2 cts.
Total fixed cost	6¼ cts.

If the average load is 1-7 cu. yd., hauled at a speed of 220 ft. per min., the cost of hauling is 4½ cts. per cu. yd. per 100 ft. of "lead." Note that this "lead" is measured on a straight line from center of pit to center of dump. The rule, then, is as follows for "average earth" when team wages are 35 cts. per hr.:

Rule IV.—To a fixed cost of 6¼ cts. per cu. yd. add 4½ cts. per cu. yd. per 100 ft. of "lead."

This is approximately equivalent to 1 ct. added for each 25 ft. of "lead." Thus, if the "lead" is 25 ft., the cost of drag scraper work is 6¼ + 1, or 7¼ cts. per cu. yd.

The cost of foreman's wages is ordinarily about ¾ ct. per cu. yd., and wear on scrapers, etc., will add another ¼ ct. per cu. yd.

The cost of excavating and hauling fairly stiff clay may easily be 30% more than the above costs for "average earth."

Cost by Wheel Scrapers.—The wheel scraper is a development of the drag scraper, being a steel scoop low hung between two wheels. The following are common sizes of wheelers:

	Weight, lbs.	Capacity. Listed, cu. ft.	Capacity. Actual Struck Measure, cu. ft.
No. 1	340—450	9—10	7½—9
No. 2	475—500	12—13	8¾
No. 2½	575	14	12
No. 3	625—800	16—17	15½

The "listed" capacity is the capacity given in catalogs. The "actual struck measure" capacity is the exact contents of the bowl when level full of loose earth, and it should be remembered that

about one-fifth of 20% should be deducted from this to get the actual struck capacity of earth measured "in place" before loosening.

Large wheelers, even in light soils, and small wheelers in tough soils, seldom leave the pit full of earth, but at the back end of the bowl there is usually a wedge-shaped unfilled space. I have found the average load, "place measure," carried by wheelers is as follows:

No. 1	1/5 cu. yd.
No. 2	¼ cu. yd.
No. 2½	⅓ cu yd.
No. 3	4/10 cu. yd.

A snatch team, to assist in loading, is generally used with a No. 2 wheeler, and always with a No. 3 wheeler.

On long hauls it is advisable to have men with shovels to heap the bowl full of earth, using a front gate on the wheeler to prevent loss of material in transit.

The lightest No. 1 wheelers made are to be recommended where leads are very short and rises steep, that is, wherever drag scrapers are ordinarily used, for they move earth more economically than drags. Where soil is very stony, or full of roots, drag scrapers are to be preferred, since they are more easily and quickly loaded under such conditions. With wheelers, as with drag scrapers, add 50 ft. to the actual "lead" for turning and maneuvering the teams, equivalent to half minute of team time each trip. Another half minute is lost in loading and dumping.

The fixed costs for the three common sizes of wheelers are as follows for "average earth," when wages are 15 cts. per hr. for laborer and 35 cts. per hr. for team (with driver):

	—Cents per cu. yd.—		
	No. 1.	No. 2.	No. 3.
Lost team time loading and dumping....	1.5	1.2	0.8
Wages of man loading	0.8	0.8	1.5
Plowing	1.5	1.5	1.5
Extra travel of team in turning, etc......	1.5	1.2	0.7
Snatch team	...	1.5	1.5
Wages of man dumping	...	...	0.8
Total, cts. per cu. yd	5.3	6.2	6.8
Size of load hauled, cu. yds	1/5	¼	4/10

A snatch team is usually used with No. 2 wheelers, and in short-haul work there is usually a dump man also.

In easy soils, I have had one snatch team assist in loading 300 cu. yds. per day, so that this item may be less than above estimated; and under the same conditions another ⅓ ct. per cu. yd. or more may be saved in wages of men loading and dumping. There are usually two men required to load a No. 3 wheeler, which accounts for the higher cost of this item in the No. 3 column.

The cost of wheeler work, based upon the foregoing data, is as follows:

Rule V.—To a fixed cost of 5¼ cts. per cu. yd. for No. 1

wheelers, or 6¼ cts. for No. 2 wheelers, or 6¾ cts. for No. 3 wheelers, add the following per cu. yd. per 100 ft. of "lead": 2¾ cts. for No. 1 wheelers; or 2 1/5 cts. for No. 2 wheelers; or 1⅝ cts. for No. 3 wheelers.

The cost of foreman's wages and repair of wheelers will add about 1 ct. more per cu. yd.

If the "lead" is 50 ft. and No. 1 wheelers are used, the cost is 5¼ cts. + (½ × 2¾ cts.), or 6.7 cts. per cu. yd., exclusive of foreman's wages.

Cost by Fresno Scrapers.—The ordinary four-horse fresno scraper has a bowl 13 ins. high, 18 ins. wide and 5 ft. long, giving a struck measure capacity of slightly more than 8 cu. ft.; but in almost any soil, except dry, running sand, the earth will heap up 6 or 8 ins. above the top of the bowl, and will extend quite a distance beyond the front of the bowl. One carefully measured fresno load of clayey earth contained 19 cu. ft. of loose earth, which compacted to 16½ cu. ft. when rammed in 4-in. layers in a box. Several other large loads gave almost the same results after being hauled 100 ft. over a level road.

Mr. Geo. J. Specht has stated that on a down hill haul, loads will average 35 cu. ft. and occasionally run as high as 44 cu. ft. However, this could only occur with light, damp soil and on a down hill pull where much material could be drifted ahead of the fresno scraper. I have never measured any loads of that size.

On level hauls, or on uphill pulls, it is not ordinarily safe to count on more than ½ cu. yd. (measured in cut) per load, although under favorable conditions the average load may be 25 to 50 per cent greater, while under unfavorable conditions it may be 25 per cent less.

If the delays in loading and dumping are excluded, the team can be counted upon to travel about 200 ft. per minute. It requires some room in which to maneuver scrapers of any kind, no matter what method of hauling the teams is adopted. Hence one must not measure the average distance in a straight line from center of the cut to the center of the fill, and call that the average haul, for that is the average "lead," which is considerably shorter than the actual haul.

When the daily wage of a driver is $1.50 and that of each of the four horses is $1, a total of $5.50 per fresno, the following rule will give the average cost of fresno work, not including plowing, trimming or supervision.

Rule VI.—To a fixed cost of 5 cts. per cu. yd. add 1¾ cts. per 100 ft. of "lead."

The fixed cost of 5 cts. includes traveling the extra distance in loading, etc., the slower speed in loading, the shifting of the gang to newly plowed ground, etc., and it includes 1 ct. for plowing the earth. The hauling cost of 1¾ cts. per 100 ft. is based upon a traveling speed of 200 ft. per minute (when not delayed by loading, dumping, etc.) and upon the assumption that the average load is

½ cu. yd., wages of four horses and driver being $6 per 10-hr. day. In applying the rule never assume a "lead" shorter than 50 ft.

"Lead" in feet.	Cu. yds. per fresno per day.
50	120
100	100
150	87
200	75
250	67
300	60
350	55
400	50

I have never measured any fresno loads that had been hauled as far as 400 ft., and I doubt very much whether fresno loads hauled that distance would average as much as ½ cu. yd., due to the loss that occurs en route.

If the soil is not of a kind that heaps up and drifts well in front of the fresno, the average load will probably not exceed 9 cu. ft. or ⅓ cu. yd., particularly on long hauls. In which case the rule becomes:

Rule VII.—To a fixed cost of 5 *cts. per cu. yd. add* 2⅔ *cts. for each* 100 *ft. of "lead."*

Then, for a 600-ft. "lead" the cost would be 5 + (6 × 2⅔), or 21 cts. per cu. yd. This checks very closely with Mr. Walter N. Frickstad's data for a 600-ft. haul with fresnos, as given in *Engineering-Contracting,* Nov. 3, 1909.

Based upon this last rule the cost of fresno work is as follows for different leads:

"Lead" in feet.	Cts. per cu yd.	Cu. yds. per fresno per day.
50	5½	109
100	7	86
150	8½	70
200	10	60
250	11½	52
300	13	46
400	16	37
500	19	31
600	22	28

Bear in mind that the above costs do not include cost of foreman's wages, which ordinarily ranges from ½ to 1 ct. per cu. yd. Dressing roadbed and slopes will usually cost an additional ½ ct. per sq. yd. of surface trimmed.

I have assumed a 10-hr. working day, but it is my opinion that it makes little difference whether the day is 8 or 10 hrs. long, for the horses can be "crowded" harder on the shorter day, and thus cover the same mileage as on the longer day.

I have assumed that each fresno is loaded as well as dumped by the driver. This is one of the great advantages of a fresno over a drag scraper. However, in tough soils it is generally wise to have one man with each string of fresnos to load them.

A four-horse fresno scraper weighs about 275 lbs. A rope should be tied to the end of the handle, so that the driver can jerk the rope

and right the bowl when he gets back to the pit and is ready to load.

The four horses are hitched abreast. The two outside horses have a "jockey stick," the ends of which are tied to their bits, and each horse's bridle is fastened to the adjoining horse's bridle by a short strap or rawhide string. Each of the two reins is divided into two lines, one line going to each horse's bridle, one of the lines from each rein going to one outside horse, and the other line to the second outside horse from it. Thus the left hand rein pulls the left hand outside horse and the right hand inside horse, these two horses guiding the other two horses by the bit straps. The right hand rein controls the other two horses.

Due to the fact that fresno scrapers can ordinarily be loaded by the drivers, it is not necessary to work several fresnos in a string. In fact when building an embankment from two ditches, one on each side, a common method of handling the fresnos is as follows: The driver loads the fresno in the ditch, drives up the embankment diagonally, dumps the load and continues right across the embankment and down into the ditch on the opposite side, where he loads again after turning around, and returns. When working in this fashion, some foremen require all the fresnos to move in unison, so that a glance will show that none is loafing. When handled thus, however, it is not possible to plow where the fresnos are working, so some time is always lost in moving the fresno gang to newly plowed ground. This lost time has been allowed for in the rule for cost above given.

Fresno work is cheaper than drag scraper work under almost every condition that can be named.

It is not easy to fix the limit of economic haul with fresnos as compared with wheeled scrapers, principally because the size of the fresno load varies greatly in different soils. It is quite commonly believed in California that for hauls beyond 200 to 250 ft. the wheeled scraper is preferable, but in tough soils or in dry sand the fresno loads may be so small that a wheeler can compete successfully on shorter hauls. On the other hand, in soft, damp soils that heap up and drift well in front of a fresno, the economic haul may considerably exceed 300 ft.

The above conclusions are based upon the assumption that the wage of the driver equals the wage of two horses. Where horse feed is cheap and wages of men are high, it is clear that the fresno shows up more favorably, for it is one of the characteristics of fresno work that there are many horses and comparatively few men.

In solving the problem of economic earthwork in any individual case, the first step should be to measure a number of average loads of earth as they are delivered at the dump by fresnos and by wheelers. Don't measure the loads in the ditch or pit, but on the dump, for much may be lost in transit. Shovel the load of earth into a wooden box and ram it in 4 to 6-in. layers. A little time spent in thus measuring the loads accurately will enable a close estimate to be made of the actual yardage moved per day per scraper of each class, provided a boy or man is assigned for a day to the

task of tallying every load moved by a typical fresno gang and by a typical wheeler gang.

Considering the amount of money that is usually at stake, it is remarkable how often guesswork prevails where a little time spent in measuring a few loads and a day's tally of the loads would settle the matter definitely. Where a gang is moving only 1,000 cu. yds. daily, 1 ct. saved per yard means $10 a day. Yet even the most skilled foreman will find it next to impossible to ascertain the difference of a cent a yard cost between a fresno gang and a wheeler gang merely by looking at them work. I am speaking now of work by these two types of scrapers where the length of haul is such that they are almost on a parity as regards cost. Of course there are hauls where there can be no doubt at all, where it is either the fresno "hands down," or where it is the wheeler "hands down."

Cost by Elevating Graders.—An elevation grader consists essentially of a four-wheeled truck provided with a plow which casts its furrow upon an endless belt, which elevates the material and deposits it in wagons as fast as they are driven under the belt. For successful operation there must be few boulders or roots to stop the plow of the machine; and there must be considerable room in which to turn the machine, and maneuver the teams going and coming, and the ground on which the grader is working must not be too hilly. The machine does not work to advantage in narrow cuts, due to lack of room for wagons alongside. The machine is adapted to loading wagons on road work, but is especially suitable for reservoir work and the like. The machine is used in prairie soils for digging ditches and conveying the material directly into the road, but the material must afterward be leveled with a leveling scraper or road machine; and it would seem better practice to use the road scraper entirely for this class of grading without resort to the elevating grader at all. Claims have been made that 1,000 cu. yds. in 10 hrs. are loaded by the grader. Under very favorable conditions this may be done, but I have never seen a daily average of more than 500 cu. yds. place measure loaded by a grader operating in easy soil.

A grader costs about $1,000, and is hauled either by 10 or 12 horses or by a 25-hp. traction engine, the latter being usually the more economical in the long run. It requires 2 men to operate the grader, and, where horses are used, 2 or 3 men to drive the horses. Where a traction engine is used, 2 men operate the grader, 1 engineman operates the traction engine, and it is often necessary to keep a team busy part of the time hauling water for the engine, if water is not supplied by gravity or by pumps. The traction engine burns 0.6 to 0.7 ton, or 1,200 to 1,400 lbs., per 10 hrs. To furnish steam there will be required not over 8 lbs. of water per lb. of coal, or $0.7 \times 8 = 5.6$ tons of water per day. The grader travels about 150 ft. per min. when hauled by an engine, and it takes 1½ mins. to turn around at each end of its run, describing a circle of about 50 ft. diameter in turning. It takes about 15 seconds to load a wagon with ¾ cu. yd. of earth measured in

place, when the grader is traveling 150 ft. per min., so that the grader travels 40 ft. in loading a ¾-yd. wagon; then it stops for about 15 secs. until the next wagon comes up under the belt. If three-horse patent dump wagons are used—and no other kind should be used with elevating graders—the wagon load is 1¼ cu. yds., and the grader travels about 65 ft. to load a wagon.

I have seen 700 two-horse wagons, holding ¾ cu. yd. each, loaded per 10-hr. day; and, I am informed, that with good management and an easy soil, 700 wagons, holding more than 1 cu. yd. each, can be loaded per 10-hr. day. With three-horse wagons the average 10-hr. day's output on the Chicago Drainage Canal was 500 cu. yds. of top soil.

Mr. N. Adelbert Brown, C. E., of Rochester, informs me that an elevating grader was used by Thomas Holihan, in grading streets at Canandaigua, N. Y. The streets were 60 to 75 ft. wide between property lines, and 36 ft. between curbs. A traction engine was used to haul the grader, and there was no trouble in turning the engine and grader between the walk lines, which was easily within 50 ft. of space. "The efficiency of the machine was not tested fully, due to a lack of teams; but, when teams were available, 50 wagon loads, of 1½ cu. yds. each, were readily loaded in an hour. The machine was satisfactory in stone and gravel roads and stiff clay, but in light sand in some cases refused to elevate." This latter is true, however, of all elevating graders in any dry sand that will not turn a furrow.

Fred. T. Ley & Co., of Springfield, Mass., inform me that elevating graders were used by them on electric railway work in central New York state, both with traction engines and with horses. They averaged 400 to 500 cu. yds. loaded into wagons per grader per day.

No matter how short the lead, a team hauling earth from a grader must perform a large percentage of waste labor following the grader, and this is equivalent to adding about 400 ft. to the "lead." If 3 horses and a driver are worth $4.50 a day, and the load is 1¼ cu. yds., the cost of hauling is 0.6 ct. per cu. yd. per 100 ft. of haul; so that the waste distance traveled (400 ft. lead) adds 2½ cts. per cu. yd. to the cost. With wages of single horses at $1, and men at $1.50, the fixed cost is as follows, with an output of 500 cu. yds. per 10 hrs.:

	Per cu. yd.
Lost team time (400 ft. added to "lead")	2.5 cts.
10 horses on grader and 4 men	3.5 "
5 men on dump spreading	1.5 "
Interest, repairs and depreciation, $5 per day	1.0 "
Total	8.5 cts.

The rule is:

Rule VIII.—To a fixed cost of 8½ cts. add 6/10 ct. per cu. yd. per 100 ft. of lead.

It will take 6 three-horse wagons to handle the 500 cu. yds. per day where the lead is 500 ft.

It is necessary to spread the earth on the dump to prevent stall-

ing of the dump wagons, but by using a leveling scraper the cost of this item can be reduced to 1 ct. or less, instead of the 1½ cts. above given for hand work.

A traction-engine outfit will reduce the cost of operating the grader somewhat below the above given figures, thus:

	Per day.
⅔ ton coal, at $3	$ 2.00
1 engineman	3.00
2 grader operators	5.00
Interest, repairs and depreciation of engine	3.50
Total, 500 cu. yds., at 2.7 cts.	$13.50

This 2.7 cts. per cu. yd., it will be seen, is 0.8 ct. less than where 10 horses and 4 men operate the grader.

If it is necessary to pump water by hand and haul it far for the traction engine, the cost may easily be increased ½ ct. per cu. yd., or more.

In *Engineering-Contracting*, April, 1906, page 102, etc., there is an article by Mr. Daniel J. Hauer, giving costs of elevating grader work on 7 railroad jobs. The limitations of the grader for narrow thorough cuts are well shown. The average cost was as follows for an average "lead" of 800 ft., with an average daily output of 288 cu. yds. per elevating grader:

	Per cu. yd.
Loading	$0.100
Hauling	0.127
Dumping and spreading	0.029
Water boy	0.002
Foreman	0.010
Total	$0.268

The wages of the grader operators were $1.50 per 10-hr. day; laborers, $1.50; two-horse team and driver, $4.60; three-horse team and driver, $6.25. The $0.268 does not include any allowance for interest, repairs and depreciation. This is probably as high a cost for elevating grader work as will be likely to occur with the same length of haul and the same rates of wages.

Steam Shovel Data.—The size of a steam shovel is usually denoted by the capacity of the dipper in cubic yards and the weight of the whole machine in tons; both should be given, for in a hard material a smaller dipper is used than in soft material when working with the same steam shovel. The following are some of the standard sizes:

Weight, tons	35	45	55	65	75	90
Dipper, cu. yds.	1¼	1½	1¾	2	2½	3
Coal in 10 hrs., tons	¾	1	1¼	1½	2	2¼
Water in 10 hrs., gals.	1,500	2,000	2,500	3,000	4,000	4,500

The price of shovels is approximately $130 per ton for the larger sizes, and $160 per ton for the 35-ton size.

A shovel of any size is so designed that, when digging in average earth, it can average at least 3 dipperfuls per minute, when the dipper arm swings only 90°. Shovels are built to run on standard gage track, and in operating a shovel it is customary to use rails in 5-ft. lengths, so that the shovel cuts 5 ft. into a face before it is

shifted ahead. The time required to shift ahead may average as low as 3 mins., and should never average more than 5 mins., but on poorly managed work I have often seen 10 mins. consumed in shifting the shovel ahead.

"Traction shovels" weighing 26 tons, or less, may be had, and they do not require rails to run upon, but are provided with broad-tired traction wheels.

Steam shovels of small size, mounted like a locomotive crane so that they can swing a full circle, are especially adapted for loading wagons in confined places.

The width of the cut or "swath" excavated by a shovel varies from 18 ft. for the smallest shovels to 40 ft. for the largest. The height of the face of the cut is usually 15 to 30 ft. In tough material the face of the cut should not be higher than the dipper can reach, that is, 14 to 20 ft. Too high a face in treacherous, sliding material is to be avoided, for the shovel may be buried by a slide.

The height of the face of the cut has a marked influence upon the output of a shovel. If the face is only 6 ft. high and 18 ft. wide, there are only 4 cu. yds. per lineal foot of cut, or 20 cu. yds. for every 5 lin. ft. of cut. A 1-yd. shovel would excavate this in, say, 10 mins.; then, if 5 mins. were spent moving forward for the next "bite," there would be 15 mins. required to excavate 20 cu. yds., and one-third of the time would be spent in shifting the shovel. Shallow cuts are expensive not only on this account, but because a full dipper cannot be averaged when the height of the face of the cut becomes much less than one and a half or two times the depth of the bucket.

In addition to the lost time of shifting the shovel, there is more or less lost time switching cars up to the shovel. On "thorough cut" work this lost time of switching is greater than on "side cut" work. A *"thorough cut"* is practically a huge trench, in which the shovel is working at the face, so that only one or two cars can come up on the track alongside of the shovel, the car track being in the bottom of the cut. This method of attack should be avoided wherever possible. In "side cut" work a full train of cars can come alongside the shovel, one car being loaded after another until the train is loaded.

There are frequently conditions that make it cheaper in the end to use wagons instead of cars for hauling the earth away. In such cases never use a large dipper, for so much earth will spill over the sides of the wagon as to block the road and delay the movement of the wagons, even when a snatch team is used. A 1½-yd. bucket is as large as should be used for loading wagons.

Hauling With Dinkeys.—The ordinary "contractor's locomotive," or "dinkey," travels on a track of 3-ft. gage. The smallest size of dinkey commonly used weighs 8 short tons, and is listed as having a tractive pull of 2,900 lbs. on a level track. Whether the actual tractive capacity is exactly 2,900 I do not know; but it must be approximately that, for any locomotive can exert a pull of 25% of the weight on its driving wheels even on clean rails.

The loads that a dinkey can pull, however, are much over-estimated in catalogues, due to too low rolling resistances assumed for cars. It is said in some of the catalogues that the resistance to traction is 6½ lbs. per short ton. This rate applies only to the best of standard gage railway tracks with heavy rails, well ballasted, and with heavy wheel loads. On a contractor's narrow gage, light rail track, the resistance to traction is probably not must less than 20 to 40 lbs. per ton, and at the point where the cars are loaded it is doubtless more, due to the dirt on the rails. It requires almost twice as great a pull to start a car as to keep it in motion.

The resistance due to gravity is 20 lbs. per short ton per 1% of grade; but, of course, the tractive power of a locomotive falls off 20 lbs. for every ton of its own weight for each 1% of grade.

Based upon these data, and upon the assumption that the resistance to traction is 40 lbs. per short ton, an 8-ton dinkey is capable of hauling the following loads, including the weight of the cars:

	Total tons.
Level track	70
1% grade	46
2% grade	33
3% grade	26
4% grade	21
5% grade	17
6% grade	14
8% grade	10

Note.—On a poor track not even as great loads as the above can be hauled.

Due to the accidents that frequently occur from the breaking in two of trains on steep grades, and from the running away of engines, it is advisable to avoid using grades of more than 6%.

When heavily loaded, a dinkey travels 5 miles per hr. on a straight track; but when lightly loaded, or on a down grade, it may run 9 miles an hour.

The following are the average struck measure capacities of the dump cars made by one firm (variations of weight of several hundred pounds occur, according to the make):

Capacity, cu. yds.	1	1½	2	2½	3
Weight, lbs.	1,700	2,000	2,300	2,800	3,500

A car seldom averages its struck capacity of earth measured "in place," even when the car is heaped full with a shovel; for not only are there vacant places in the corners of the car, but the loose earth is 20% to 30% more bulky than earth "in place."

The number of dinkeys required to keep a shovel busy can be estimated from the data given. On short hauls (1,000 ft. or less) one very often sees only one dinkey serving a 1½-yd. shovel. In such cases the dinkey is not heavily loaded, so that it can run fast, and by having enough men to dump a train of 6 cars in 2 or 3 mins. a fairly good daily output of the shovel can be secured.

In dumping the cars, estimate on the basis of one 3-yd. car dumped by each man in 1½ to 2 mins. The men work in groups of 2 or 3 in dumping the cars, and enough men are usually provided on the dump to dump a train in 3 mins.

When two or more dinkeys are serving one shovel, and long

trains (12 cars) are being used, it would seem that very little lost shovel time would occur due to switching in an empty train; but, even under favorable conditions, I find that 1½ to 2 mins. per train are lost in switching. This is another reason why a shovel served by only one dinkey makes so good a showing on short-haul work. Still another reason is that at the time the shovel is shifting forward, the dinkey can often make its round trip; and on shallow face work this shifting of the shovel occurs frequently.

The method of using a hoisting engine and cable to move the cars is quite common in railroad work, where the hauls are short, say 1,000 ft. or less. The track is laid on a rather steep grade, at least 3% from the pit to the dump, and the cars coast down by gravity usually in trains of 4 cars holding about 2 cu. yds. each. The hoisting engines pull the cars back with a wire rope. A team of horses will have all it can do to pull a train of 4 such cars even on a slight down grade to the dump. As a matter of fact, a team that is working steadily cannot be counted on to pull more than two cars holding 3 cu. yds. each, on a level track of the kind ordinarily used in contract work.

The 3-ft. gage track commonly used is laid with rails weighing 16 to 40 lbs. per yard of single rail. A 30 or 35-lb. rail makes a track that is not easily kinked under the loads, even when ties are spaced 4 ft. centers. A 6 × 6-in. tie, 5 ft. long, is the best size. I have tried 4 × 4-in. ties, but they are easily split by the spikes, and are not of much value after being used once; whereas the 6 × 6-in. ties can be laid 4 to 6 times. After the rails and ties are delivered, and the roadway graded, such a track can be laid for $100 per mile, or $2 per 100 ft., when wages are 15 cts. per hr. And the track can be torn up and loaded on wagons for $1 per 100 ft.; there being 1 ton of 30-lb. rails and 375 ft. B. M. of 6 × 6-in × 5-ft. ties per 100 ft. of track.

In railroad work it is usually necessary to build a trestle through which the cars are dumped in making the embankment. The trestles usually consist of two posts per bent, the posts being of round timber, capped with a squared stick, and sway braced with round timber saplings. In the section on Timberwork the reader will find data on the cost of trestlework.

Summary of the Cost of Steam Shovel Work.—As above stated, shovels are so designed that about 3 dipperfuls can be averaged per minute when actually loading cars; but I find that even with well arranged tracks, and a good high face, the necessary delays of shifting the shovel ahead, switching the trains, moving the shovel back to start a new swath, etc., keep the shovel idle about half the time. Occasionally, under exceptionally favorable conditions, a shovel may average 6 or 6½ hrs. of actual shoveling per 10-hr. day.

The size of the dippers, as listed in catalogues, often refers to dippers heaped full of loose earth. I find that the actual "place measure" averages about 30% less than the listed capacity of a dipper, for not every dipper goes out full, and even if it does the earth is not as compact in the dipper as in place.

On the basis of 3 dippers loaded per minute of actual work, we have the following for dippers of different sizes:

——Dipper.——		—Output in Cu. Yds.— Steady Shoveling.	
Nominal. Yds.	Actual (average). Yds.	10 hrs.	5 hrs.
1	0.7	1,260	630
1½	1.0	1,800	900
2	1.4	2,520	1,260
2½	1.7	3,060	1,530

We see that where the shovel is actually shoveling 5 hrs. out of the 10 (and this is a good average), a 1-yd. dipper will load 630 cu. yds.; a 1½-yd. dipper, 900 cu. yds.; a 2½-yd. dipper, 1,530 cu. yds. These are not merely theoretical outputs, for I have monthly output records that show these averages for each 10-hr. shift. However, the track arrangement must be such that cars are promptly supplied to the shovel, if any such average as 900 cu. yds. per day per 1½-yd. dipper is to be maintained.

Taking the 1½-yd. dipper as the common size, we may say that in "average earth," with cars promptly supplied, 900 cu. yds. are a fair 10-hr. day's work; but if only one dinkey is used, the lost time may easily be increased to such an extent that 650 cu. yds. become a good day's work in "average earth." In hardpan, or exceedingly tough clay, the output of a shovel may fall to about half the output in "average earth"; that is, 450 cu. yds. per 10-hr. day with a 1½-yd. shovel.

The size of shovel to select for any given work depends upon the yardage of earth in each cut—not upon the total yardage in the contract. On very light cuts, such as street and road work, cellars, etc., a small shovel with a ½ to ¾-yd. dipper is usually most economic. Use a small 26-ton traction shovel, with 1-yd. dipper for small railway cuts, where moves from one cut to another will be frequent. Use a 55 to 65-ton shovel with 1½ to 2½-yd. dipper where cuts are heavy, and moves not very frequent. Use a 75 to 90-ton shovel, with 2½ to 3½-yd. dipper, on heavy cuts, where moves are infrequent. Of course a heavy shovel with a small dipper is necessary in hardpan and very tough material.

The cost of operating a 55-ton shovel is ordinarily as follows, assuming 22 days worked during the month, and 6 months worked during the year, or 132 days actually worked per year:

Shovel Crew:	Per Day Worked.
1 engineman on shovel, at $125 per mo.	$ 5.70
1 craneman on shovel, at $90 per mo.	4.10
1 fireman on shovel, at $65 per mo.	3.00
6 pitmen, at $1.75 per 10-hr. day	10.50
1 night watchman, at $50 per mo.	2.30
Total shovel crew	$ 25.60
Coal for shovel, 1¼ tons, at $4, delivered	$ 5.00
Water	3.00
Oil and waste	0.50
Interest on $7,200 shovel at 6% per year ÷ 132 days	3.25
Repairs on $7,200, 3% per mo. ÷ 22 days	10.00
Depreciation on $7,200, 6% per year ÷ 132 days	3.25
Total steam shovel crew, fuel, repairs, etc.	$ 50.60

Moving and housing shovel once during year, say, $500 ÷ 132 days	4.00
Total charges on shovel	$ 54.60
Train Crew:	
2 enginemen (on 2 dinkeys), at $3	$ 6.00
2 trainmen, at $2	4.00
6 dumpmen, at $1.75	10.50
Total train crew	$ 20.50
Coal for 2 dinkeys, 0.6 ton, at $4	$ 2.40
Water	1.50
Oil and waste	0.50
Interest on $8,000 (2 dinkeys and 24 cars), at 6% per year ÷ 132 days	3.65
Repairs on $8,000, at 1½% per mo. ÷ 22 days	5.45
Depreciation on $8,000, at 8% per year ÷ 132 days	4.85
Total train crew, fuel, repairs, etc.	$ 38.85
Moving and housing locomotives and cars once during year, same as for shovel	4.00
Total charges of locomotives and cars	$ 42.85
Track Crew and Track:	
6 men grading and track shifting, at $1.75	$ 10.50
Interest on $2,250 (rails (35 lbs. per yd.) and fastenings for 1 mile of track), at 6% ÷ 132 days	1.00
Depreciation on $2,250, at 12% ÷ 132 days	2.00
Interest on $750 (ties, at 30 cts. each, 2 miles track), at 6% ÷ 132 days	0.35
Depreciation on $750 (ties), at 10% per mo. ÷ 22 days	3.50
Total track crew and track	$ 17.35
Supervision, Etc.:	
½ superintendent, at $150 per mo.	$ 3.50
1 foreman, at $75 per mo	3.50
1 timekeeper, at $65 per mo	3.00
General management, office expenses, etc., 6% of daily payroll	4.00
Total supervision, etc.	$ 14.00
Grand total	$128.80

Summarizing we have the following daily cost and cost per cu. yd. when the daily output is 1,000 cu. yds. (or 22,000 cu. yds. per month):

	Per day.	Per cu. yd. cts.
Shovel expenses	$ 54.60	5.46
Train expenses	42.85	4.29
Track expenses	17.35	1.73
Supervision, etc.	14.00	1.40
Total	$128.80	12.88

Tough material and unfavorable conditions frequently reduce the daily output to 600 cu. yds., and run the cost up to 21 cts. per cu. yd.

The most variable of the four main items of daily expense is Track Expense. Often a large crew of men is kept busy grading for new tracks, although it is rare that more than 10 or 12 men are thus engaged for each shovel crew.

The estimated percentages for repairs and depreciation are lib-

eral, but it must be remembered that repairs increase as the machines grow older, and that a high allowance should be made for depreciation to cover obsolescence, i. e., the "getting out of date" or behind the times.

Depreciation of ties is especially rapid in contract work, due to the destruction that occurs from frequent track shifting. Depreciation of rails is also rapid, due to their becoming kinked.

The foregoing itemization of cost should be taken merely to represent a fairly typical example, but each particular case will have its varying conditions that must be considered.

Where temporary trestles must be built to carry the cars out over proposed fills, as is common on railway work, the cost of the trestles must be added to the above figures. The cost of trestlework can be estimated from data given in the section on Piling and Timberwork, bearing in mind, however, that much lighter timbers can be used for dinkey locomotives and trains than for standard railway tracks. It should also be remembered that round poles can usually be secured for the legs or posts of trestle bents, and that each bent usually has only two legs. The squared stringers, ties and caps can usually be recovered, but the posts, sills and sway braces are buried permanently in the fill.

Cost of Digging a Well or Cesspool.*—Circular wells or holes are often dug for water supply and for cesspools around buildings.

A well was dug on Long Island in a clay material with an occasional boulder. The material was stiff enough to stand up without shoring. The hole was 8 ft. in diameter and 24 ft. deep. For two days two men did the work, but, when a bucket had to be used, another man was added to the force. A three-legged derrick, with a crank on it, was used to hoist the bucket of earth. The excavation was made entirely with picks and shovels. There were 1,305 cu. ft. of material excavated, or about 48 cu. yds. A 10-hr. day was worked. The cost of the work was as follows:

2 men 2 days, at $1.50	$ 6.00
3 men 5 days, at $1.50	22.50
Total	$28.50

This gives a cost of 60 cts. per cu. yd. for excavating and hoisting the material and dumping it on the ground by the side of the hole. This cost is quite reasonable for this work.

Cost of Trenching, Cross-References.—Data on this subject will be found in the following sections of this book: Waterworks, Sewers, and Miscellaneous Costs. Consult the index under Trenches.

The Cost of Backfilling a Trench With a Scraper.†—Fig. 1 shows a Doan Ditching Scraper for back filling trenches or ditches.

To backfill a trench, a rope or chain about 20 ft. long is fastened to the cable chain on the scraper, and a team is hitched on to the end of the rope. The team, of course, works on one side of the trench. The scraper weighs only 75 lbs., and can be dragged back

Engineering-Contracting, Oct. 28, 1908.

†*Engineering-Contracting*, January, 1906, p. 11.

by one man, although some contractors prefer to have two men on the scraper, especially when the men are small.

In 10 hrs. a team and driver and one man on the scraper backfilled 400 lin. ft. of trench 2 ft. wide by 7 ft. deep. This is more than 200 cu. yds. backfilled at a cost of 2½ cts. per cu. yd. With two men on the scraper, and working very hard, as much as 700 lin. ft. were backfilled in a day, which is equivalent to less than 2 cts. per cu. yd. In this case no tamping was required, but, even where tamping is called for, a scraper is much cheaper than a shovel for backfilling.

While good work can be done with the ordinary drag scraper, it is not so good a tool for backfilling as that described above, for three reasons: First, because a Doan scraper is lighter; second, because a drag scraper is narrower; and third, because a drag

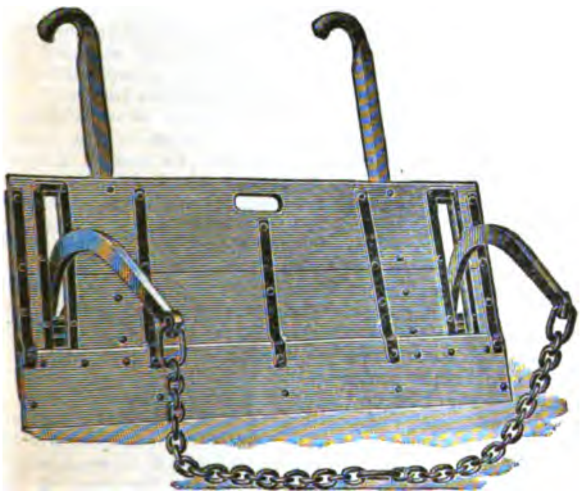


Fig. 1. Doan Scraper.

scraper is not so quickly dumped. The Doan scraper is made of oak, shod with steel on the cutting edge. This cutting edge is 4 ft. long, which means a good wide swath cut at each forward pull. In addition to its use for backfilling, the scraper is also suited for use in digging ditches, leveling embankments, etc. The scraper is made by the Sidney Steel Scraper Co., of Sidney, Ohio.

Prices for Drainage Ditch Work.*—The following figures on ditch construction in Minnesota were given by Mr. George A. Ralph, State Drainage Engineer, in a paper before the Minnesota Sur-

*Engineering-Contracting, July 10, 1907.

veyors' and Engineers' Society. The figures are the average prices and are based on contract prices for work on which Mr. Ralph was engineer; they cover a period extending from 1886 to 1906:

	Per cu. yd.
Slip scraper work:	
Not exceeding 6 ft in depth	$0.10
Not exceeding 10 ft. in depth	0.12
Not exceeding 12 ft. in depth	0.14
Elevating grader work	0.08
Shovel work, 2 to 6 ft. deep	0.15
Shovel work, 2 to 10 ft. deep	0.20
Hayknife work, 2 to 4 ft. deep	0.12
Hand labor in timbered swamps	0.15 to 0.20
Good dredge work	0.08
Dredge work, unfavorable conditions	0.10 to 0.14
Capstan ditch, plow work	0.40 to 0.60

Cost of Boring Test Holes in Earth.*—For the purpose of prospecting, testing foundation sites, well drilling, etc., it is often necessary to bore through sand, gravel, clay, etc. There are four common methods of boring in earth: (1) By means of an earth auger; (2) by a churn drill; (3) by driving a pipe and washing out the earth inside the pipe with the aid of a force pump, called "wash boring"; and (4) by post hole diggers of various forms.

Any of these methods (except the third) may be used either with or without a casing pipe to preserve the sides of the hole from crumbling in, and any kind of power may be used. In soil that crumbles readily a casing pipe is always necessary where the hole must be sunk to any considerable depth; but by the exercise of a little ingenuity it is often possible to bore even in dry sand without using a casing pipe. We are indebted to Mr. J. M. Rudiger for the following hint, which will be found exceedingly useful in boring in sand up to depths of about 30 feet: Pour one or more barrels of water on the sand at the site of the proposed bore hole. The water will pass vertically downward, spreading no great distance laterally. In the sand thus made damp, an earth auger may be used to bore without any caving in of the sides. If the hole is to be used as a well, lower a casing pipe into it after water has been struck.

Cost of Hand Auger Prospecting.—Mr. Charles Catlett is authority for the following methods of prospecting for deposits of hematite in Virginia. The set of tools consists of a steel auger bit twisted into a spiral (4 turns) 2 ins. diam., the steel of the bit being ¼ in. thick and 13 ins. long and provided with a split point. This bit is welded to an 18-in. length of 1-in. wrought pipe having a screw threaded end. Another chopping bit for use in hard material is made of 1⅝-in. octagon steel with a 2-in. cutting edge, and is welded to a length of 1-in. wrought pipe. As many lengths of 1-in. wrought pipe are provided as necessary, with screw couplings. An iron handle, 2 ft. long, is provided with a central eye and with a set screw so that it can be fastened to the 1-in. pipe at any place. A 10-ft. length of 1¼-in. pipe, threaded at each end for connection to the 1-in. pipe, is provided for use in giving weight to the pipe drill rods in churning. The other tools are: A sand pump of 1 or 2 ft. of 1-in. pipe with a leather valve, and cord for lowering it;

*_Engineering-Contracting_, January, 1906, p. 11.

two pairs of pipe tongs; two monkey wrenches; 25-ft. tape; flat file; spring balance; oil can; water buckct, etc. In boring through soft material, the auger is rotated by two men, raised every few minutes, scraped clean, and the handle fastened higher up on the rods. In hardpan or rock the churn bit is used, and the sludge is removed either with the auger or with the sand pump. The greatest depth penetrated with this outfit was 80 ft. Up to a depth of 25 ft. two men suffice; from 25 to 35 ft., three men; 35 to 50 ft., three men, the third man standing on a rough timber frame 15 or 20 ft. high, so that the pipe need not be unjointed when raised. For depths of 50 ft. more the pipe is unjointed when raised. The following are progress records on eight holes:

HOLE A.

Through.	Ft.
Sand and clay	2
Yellow clay	6
Hematite ore	5
Clay and ore	3
Total	16

Time of 2 men. 10 hrs.
† Cost per ft., 18.7 cts.

HOLE B.

Through.	Ft.
Yellow clay	12
Black flint	½
Yellow clay	2½
White sand	1
Sandstone	2
Total	18

Time, 2 men, 5 hrs.
† Cost per ft., 8.3 cts.

HOLE C.

Through.	Ft.
Sand	1
Shale	4
Yellow clay and sand	9
Sandstone	5
Total	19

Time, 2 men, 8½ hrs.
† Cost per ft., 13.4 cts.

HOLE D.

Through.	Ft.
Yellow clay	17½
Solid ore	8½
Total	26

Time, 2 men, 6 hrs.
† Cost per ft., 6.9 cts.

HOLE E.

Through.	Ft.
Sand and gravel	1
Clay	28
Total	29

Time, 2 men, 5 hrs.
† Cost per ft., 5 cts.

---

† Assuming wages at 15 cts. per hour.

HOLE F.

Through.	Ft.
Loose slide	3
Clay	7
Shale ore	6
Wash ore	24
Total	40

Time, 2 men, 11 hrs.; 3 men, 4 hrs.
† Cost per ft., 12.7 cts.

HOLE G.

Through	Ft.
Sand and drift*	19
Clay	33
Total	52

Time, 2 men, 15 hrs.; 3 men, 4 hrs.
†Cost per ft., 12.1 cts.

HOLE H.

Through.	Ft.
Sand and drift	12
Clay	51
Total	63

Time, 2 men, 5 hrs.; 3 men, 25 hrs.
†Cost per ft., 20.2 cts.

*Sandstone drift. †Assuming wages at 15 cts. per hour.

Cost of Wash Borings on a Canal Survey.‡—Mr. A. W. Saunders is author of the following:

These data were obtained on a survey of 95 miles, covering the operations of a year. The line ran over a little rough country, two rivers and a lake. The land was not "rocky," though there were some stony plots of course.

The equipment was complete in all its details, thus enabling an economic and thorough prosecution of the work, i. e., making test borings to locate the "rock line" or elevation of the rock in the earth, on a survey of a ship canal.

Two parallel lines were run 500 to 1,500 ft. to the right and left of the main line. This necessitated a systematic and constant hustle to prevent a stalling of the work, for one machine often was on one side of a river and others scattered over a mile of ground.

Fig. 2 is the Carpenter wash drill. The pump is to the left and rear of the hammer. This machine, equipped for 120 ft. of work with pump, 500 ft. of 1½-in. water pipe and all necessary accessories, will now cost $200. This machine is readily transported by hand through swamps, marshes or even rivers; and, with its tool box, makes but a small one-horse load. The illustration shows a machine rigged to put down deep holes (100 ft.). Fig. 3 shows method of pulling the pipe.

Two 2-oz. sample bottles are shown (just below the foreman's knee). The notes are recorded in his note book suitably ruled; samples of the borings are obtained, the bottles labeled and all sent into the office where the whole is plotted; the notes and samples are filed.

‡*Engineering-Contracting*, Dec. 9, 1908.

Fig. 2. Wash Drill.

Fig. 3. Pulling Pipe.

Fig. 4 is the Sullivan earth drill. Water is forced through the drill rods down to the foot or "shoe" of the casing and then up in the casing bringing with it the material drilled through, a sample of which is thus obtained and its "condition" noted. This

Fig. 4. Earth Drill.

machine is not as easily moved as the other and trails along behind a wagon. It will cost $300 completely equipped for 100 ft. of work with 500 ft. of 1½-in. water pipe, pump, etc. A portable blacksmith or repair shop, 12 x 12 x 8 ft., equipped with pipe working tools, forge, etc., is figured in with the cost given below.

The total amount of work in one year's continuous work of 4 crews (increased to 8 crews for 5 months), was 750 holes aggregating 33,711 ft. exclusive of water. The cost of the entire outfit (8 machines complete, repair shop and tools) was considered sunk in the enterprise. The total cost was $21,862.12, or $230 per mile of survey, or 64.9 cts. per ft. of boring, divided as follows:

Salaries and subsistence	$18,593.46
Traveling expenses	189.48
Plant, tools, repairs	2,242.41
Explosives	508.32
Freight and express charges	129.17
Office expenses	199.28
	$21,862.12

This includes its share of the expense of the chief engineer, assistant engineer and other engineering work, as well as the plotting, etc. The actual cost of all borings, exclusive of the cost of the plant, repairs, superintending, freight, express, traveling and incidentals, was 48.7 cts. per ft. of boring, much of it through hard compact material.

The scale of wages was: Assistant engineer, $150 per month; superintendent, $100; assistant superintendent, $60; foreman, $45; laborers, $30; all a monthly rate, with subsistence furnished. A teamster with a team received $90 per month and "found" himself and team. A regular crew consisted of a working foreman and 4 men.

I used a Carpenter machine on the Wachusett Aqueduct, Massachusetts, and often obtained a sample of earth at a depth of 240 ft. in one-half day.

On another job in New York state, a Carpenter, with some of my Massachusetts men, was 17 days on one hole, including lost time by reason of bad weather, breakages and 2 Sundays; 55 half-pound sticks of dynamite were used blasting and blowing boulders out of the way. This was an unusual condition, yet I quote it, as I had to meet it and overcome it. It figures in with the cost.

On water the machines are set up on rafts 17.5 x 24.5 ft. composed of timbers, planks and oil barrels and constructed so as to allow the raft to be moved away from the pipe should occasion require.

There need be but little time lost during the winter. Greater care is necessary, however, to prevent the pumps and pipes from freezing at night.

Comparing the working of the two types of machines, during one-quarter of the year (3 months), the Carpenter machine drove 21 holes to a total depth of 1,501.6 ft. at a total labor cost of $760.35, explosives and freight $22.69, which is equivalent to 52.1 ct. per ft.

The Sullivan machine drove 22 holes in the same time to a total depth of 1,384.6 ft. at a labor cost of $687.04, explosives and freight $32.48, which is equivalent to 51.9 ct. per ft.

Comparing these two same machines on a single hole each, we have:

	Carpenter.	Sullivan.
Loose material	0.0 to 42.6	0.0 to 53.3
Hard packed	42.6 to 72.0	52.3 to 74.5
Rock	72.0 to 73.8	74.5 to 75.8
Time boring (including 1 rainy day)	3.85 days	4.25 days
Cost per foot	43.7 cts	45.8 cts
Dynamite (40%)	3.5 lbs.	5 lbs.
Electric exploders	7	5
Time removing drill rod	9 mins.	13 mins.
Time removing casing	39 mins.	30 mins.

Other comparisons might show advantage to the other machine.

As our business was to locate the rock, I caused the men to drill into and blast upon it, thus making sure of it. The rock drills come along later, but are not subjects of this article.

Neither of these machines is adapted to drilling in rock. They can drive the casing to the rock and no further.

Cost of Wash Drill Borings on a Canal Survey.*—In surveying in 1897-1900 the several possible routes for the proposed ship canal or deep waterway connecting the Great Lakes with Atlantic tide waters the character of the excavation was sought by making 25 diamond drill borings and some hundreds of wash drill borings along the various routes. In the following paragraphs we summarize from the scattered data in the report of the Board of Engineers such facts as are given regarding the methods and costs of making the wash borings. These figures are not so complete in detail as might be wished, but, with the omissions kept in mind, should prove a reasonably good guide for engineers about to undertake similar work. In presenting the records we shall take up the several routes separately. First, however, some of the features common to the work as a whole will be mentioned.

Organization.—The organization of the boring parties on the several routes varied somewhat. Usually, however, they comprised for each route a superintendent having charge of all the boring gangs and one or more boring gangs composed of a foreman, three or four laborers, and a teamster with team and wagon. The wages paid are not given in the report, but for similarly organized gangs for diamond drill work they were as follows: Superintendent, $125 per month; foreman, $100 per month; laborers, $55 per month; teamster with team and wagon, $75 to $90 per month. It is fair to assume, since the time and location of the borings were the same and the work was done for the same employer, that about the same wages were paid to the wash boring gangs.

Method of Borings.—The boring process was the usual one of the method, but the outfits used varied considerably. Whatever the outfit the process consisted in alternately "driving casing" and "drilling" until "bottom" was reached. Where obstructions were encountered that could not be passed by drilling, they were removed by pulling the drill rod and lifting the casing 3 or 4 ft. and then firing a stick or two of dynamite at the bottom of the hole.

Routes.—In making the surveys, two routes were considered for getting from Lake Erie to Lake Ontario. One was from Tonawanda via Lockport to Olcott and the other was from Lasalle below Tonawanda to Lewiston, both on the Niagara River. Two routes were also considered for getting from Lake Ontario to the Hudson River. One route was from Oswego via the Oswego River, Oneida Lake and the Mohawk Valley to Norman's Kill on the Hudson, and the other was along the St. Lawrence River to Lake St. Francis, then up Lake Champlain and across country to the Hudson River.

Tonawanda-Olcott and Lasalle-Lewiston Routes.—The borings for these routes were taken on sections 1,500 ft. apart and were carried to rock or to a depth below the bottom of the proposed 30-ft. channel. On the Tonawanda-Olcott route the materials penetrated were sand and gravel and sand, clay and sand, hard clay and hardpan,

**Engineering-Contracting*, March 27, 1907.

and on the Lasalle-Lewiston route they were sand, gravel, clay and hardpan. The force making the borings consisted of one superintendent and three boring parties, each composed of a foreman, three laborers and a teamster with a team to haul water and move the machines from hole to hole. In all 404 holes were bored to an aggregate depth of 9,624 ft. The cost of the work was as follows:

Item.	Total.	Per foot.
Salaries	$5,552.11	$0.5769
Traveling expenses	123.92	0.0128
Plant	649.05	0.0673
Explosives	223.87	0.0232
Freight and express	0.70	......
Office expenses	33.00	0.0034
	$6,582.65	$0.6863

These figures do not include the cost of surveys locating the bore holes, but they do include the total cost of the plants which was considered sunk when the work was completed.

Oswego-Mohawk Route, Western Division.—The borings on the Western Division of the Oswego-Mohawk route extended from Oswego to Rome and comprised the work in Peter Scott's swamp, Oneida Lake and Oswego River and Oswego Harbor. For the Oswego river and harbor work the machines were mounted on small flatboats with open wells at the center. The work on Oneida Lake was done through the ice. In all 750 holes were bored to an aggregate depth of 33,711 ft. and including the depth in water. The cost of the work was as follows:

Item.	Total.	Per foot.
Salaries	$19,645.96	$0.5827
Traveling expenses	219.75	0.0065
Plant	3,035.00	0.0900
Explosives	508.32	0.0091
Freight and express	203.77	0.0065
Office expenses	199.28	0.0059
Total	$23,812.08	$0.7007

Oswego-Mohawk Route, Eastern Division.—The work on this route comprised 290 soundings by hand with a steel rod and 1,562 actual borings, amounting together to 55,521 ft. aggregate depth. As indicating the character of the boring the following table is given:

Earth	7,611
Sand	20,706
Clay	9,880
Blue clay	177
Gravel	2,815
Shale	161
Hardpan	100
Quicksand	1,529
Sand and gravel	2,728
Sand and clay	3,176
Clay and gravel	760
Sand and shale	262
Clay and shale	902
Gravel and stone	105
Gravel and boulder	177
Hardpan and boulder	87
Hardpan and stone	36
Sand and cobble	63

Gravel and shale	292
Sand, gravel and stone	77
Sand, loam and mud	900
Sand, clay and gravel	1,843
Gravel and cobble	91
Mud	417
Rock	626
Total penetration, ft	55,521

Four types of machines were used on the work, two being manufacturers machines, one a Pierce well boring machine and one a Sullivan wash drill, and two being home-made affairs. The first of these latter consisted of a simple tripod, with a pulley at the apex and a rope passing over the pulley and attached alternately to a wooden maul for driving casing and to the drill rod. The second of these home-made devices was more elaborate. It consisted of a frame like a small pile driver, that is, two leads with back braces mounted on base timbers. The leads were 15 ft. high and the distance between the bottoms of the leads and back braces was 4 ft. The base extended 2 ft. in front of the leads. A pulley between the leads at the top and one set in brackets in front of it provided for handling the hammer and the drill rods. The hammer was of iron, with a hollow in the bottom for a wooden cushion. In operation the machine was guyed by two wire ropes. It could be loaded onto a two-horse wagon in 15 minutes and unloaded and set up in the same length of time.

The boring gangs each consisted of a foreman, three or four laborers and a teamster and double team. A superintendent of borings had charge of all the gangs. The borings varied from a few feet to 190 ft. in depth. The cost of the work was as follows:

Item.	Total.	Per ft.
Salaries	$26,470.80	$0.4769
Traveling expenses	687.62	0.0124
Plant, repairs and tools	2,287.03	0.0412
Explosives	182.20	0.0033
Freight and express	131.56	0.0027
Office expenses	298.08	0.0054
Total	$30,057.29	$0.5419

Champion Route, Ogdensburg to Lake St. Francis.—The borings along this route were made partly on land and partly in water, using a Sullivan machine. The division was as follows:

Item.	No. holes.	Ft. depth.
Sand borings	148	7,052
Water borings	151	2,123
Total	299	9,175

The cost of the work was as follows:

Item.	Total.	Per ft.
Salaries	$6,103.12	$0.6552
Traveling expenses	438.37	0.0477
Plant, repairs, tools	830.92	0.0905
Explosives	319.38	0.0347
Freight and express	72.54	0.0078
Office expenses	54.54	0.0059
Total	$7.818.87	$0.8418

Champlain Route, Hudson River Division.—This line of borings began in Lake Champlain at Port Henry and ran to Whitehall, thence across country to Fort Edward on the Hudson River and thence down the river to the State Dam at Troy. From Troy to Fort Edward one party consisting of a foreman, three laborers and a teamster and 2 horses made the borings on land, and one party consisting of a foreman and three laborers made the borings in the river. At Fort Edward the river party was transferred to land, giving two land parties to Whitehall. For the river work a catamaran was used since it could be taken apart and carried around dams. On Lake Champlain the borings were made through the ice. As most of the work was done in cold weather it was necessary to house the machine to keep the pumps and water swivel from freezing. A small shanty was built on runners and hauled from hole to hole. It had trap doors in the floor and roof and contained a stove. With this arrangement boring was carried on successfully at —30° F. The materials penetrated on Lake Champlain were silt and sand and boring was very easy as is indicated by the fact that 20,169 lin. ft. of borings were made for $2,268, or 11.24 cts. per lin. ft. The itemized cost of the borings as a whole was as follows:

Item.	Total.	Per ft.
Salaries	$6,288.23	$0.1083
Traveling expenses	156.49	0.0027
Plant, repairs, tools	561.27	0.0097
Explosives	40.74	0.0007
Freight and express	50.40	0.0008
Office expenses	74.12	0.0013
Total	$7,171.25	$0.1235

The total aggregate depth of hole was 57,991 lin. ft.

Hudson River Survey, Hudson to Troy, N. Y.—The borings along this line were made with an outfit mounted on a catamaran and on scows; silt, clay, coarse and fine sand, gravel and boulders were the materials penetrated. A 2½-in. casing and "B drill rods," with X-bits were used. The drilling gang consisted of one foreman and three laborers. For removing obstructions 40% Atlas powder was used, from one-half stick to two sticks for a charge. To get some of the holes below the depth required for a 30-ft. channel or to rock required from 10 to 30 shots. In all 1,385 borings were made to an aggregate depth of 28,965 ft. The cost of the work was as follows:

Item.	Total.	Per ft.
Salaries	$5,652.57	$0.1951
Traveling expenses	299.89	0.0104
Plant, repairs, tools	1,105.62	0.0381
Explosives	105.98	0.0037
Freight and express	68.63	0.0023
Office expenses	39.71	0.0011
Total	$7,272.40	$0.2507

Cost of Boring Test Holes.*—In making test borings most machines use water to wash up the material or to make the drilling easier, hence these borings are called "wash borings." The water changes some earths materially, softening some and washing away fine sands. For this reason wash borings are not always satisfactory, where samples of the earth are desired. A machine that will do this work without water. and, at the same time, takes a core, is of great value to engineers and contractors.

Fig. 5 shows a light, inexpensive and portable machine that will do this work quite cheaply. Its operation is simple, and the general principle is as follows:

The drilling is done with one of several tools—adapted to the particular kind of material being drilled—attached to the drilling rod. The tool and rod are operated inside the casing by the men on the platform, who raise and drop them like a "churn" drill. The men on the ground rotate the casing, which has a sharp cutting shoe on the lower end. The casing, with its burden of platform and men, thus keeps cutting and sinking into the ground several inches ahead of the tool. A horse may be substituted for the men who rotate the casing.

The material which enters the casing is drilled and forced into a sand pump at the same time. The pump is occasionally lifted out of the casing, emptied and the contents noted. Any material can be penetrated until the solid bed rock is reached. An accurate core is obtained, and the exact nature of the ground drilled is readily shown.

Four-inch pipe is generally used, with a special coupling that makes a perfectly flush joint; that is, all of the couplings have the same outside diameter as the pipe, which makes it very easy either to sink or remove this casing. Instead of the 4-in. pipe or casing, 3-in. or even 2½-in. casing can be used if desired, and it will make more rapid work, but of course would give a smaller core.

After the hole is finished, the pipe is easily withdrawn because the casing, having been constantly rotated, is always loose, both while sinking and removing.

In estimating the cost of operating this drill there is little else to be calculated besides the labor, as the repairs constitute a small part of the operating expense. Of the laborers employed, one must be a foreman or driller, another an ordinary pipeman, and the balance of the crew common laborers. When the casing or piping with its platform is rotated by a horse, instead of the men on the ground, it effects quite a saving in the cost by dispensing with three or four men. If the ground does not contain heavy boulders, and the holes are not over 35 of 40 ft. deep, six men will be sufficient, or three or four men and a horse; the cost of this crew will generally be not more than $15.00 per day.

With the 4-in. size hole 50 ft. of hole per day have been drilled at a cost of 30 cts. per foot. Twenty-five to thirty feet of hole per

*_Engineering-Contracting_, Jan. 29, 1908.

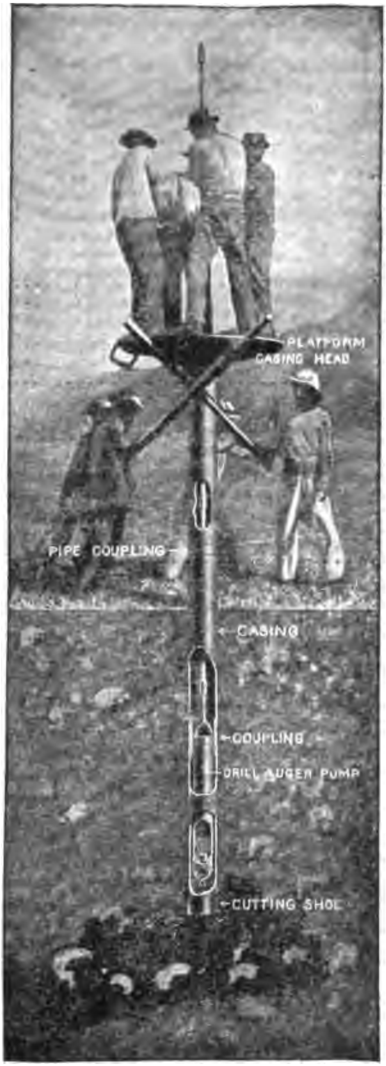


Fig. 5. Hand Drill.

day will be averaged through hard cemented gravel containing boulders.

Mr. Thos. G. Ryan used one of these drills on Long Island putting down a number of holes through sand and gravel, with occasional strata of clay, and in some cases encountering large boulders. About 40 test borings were made, each hole averaging 59½ ft., the total lineal feet drilled being 2,454. The time consumed in this work was 73 days, working 9 hrs. per day. The cost given below includes the drilling, drawing the casing, and moving and setting up drill, thus covering a number of removals over a considerable period of time.

The total cost of the work was:

1 foreman 73 days, at $4.00	$292.00
1 pipeman 73 days, at $3.00	219.00
3 laborers 73 days, at $1.50 each	328.50
1 horse 73 days, at $1.00	73.00
Depreciation, interest, renewals and incidentals	81.76
Total cost	$994.26

The average work done each day was 33.6 ft., which gives the following unit cost:

	Per lin. ft.
Foreman	$0.119
Pipeman	0.089
Laborer	0.134
Horse	0.030
Interest, repairs, deprec., etc.	0.033
Total	$0.405

The machine is the Empire Hand Drill, made by the New York Engineering Co., 2 Rector St., New York City.

In this article* we give the work of a hand drill used for prospecting in Colombia, South America. The drill was an Empire Hand Drill, manufactured by the New York Engineering Co. of New York. The work was done under the direction of Mr. Clarence R. Snow, during the autumn of 1908.

The work was done with native peons or Indians, who had never seen machinery of any kind before. The country in which the holes were being sunk was covered with forest, the bush and undergrowth in many places being very heavy. To move the drill from hole to hole a narrow path was cut through the undergrowth 6 or 7 ft. high. A small flat bottom boat was used to carry the drill across the river, there being consumed about half an hour to do this. As there are no roads in Colombia it would be almost impossible to work a steam drill, owing to the difficulty of moving it from place to place.

Four men were used to turn the casing, and four men did the drilling, an additional man being used for cutting trails. The entire crew was used to draw the casing and move the drill from hole to hole. The following is a record of seven days' work.

First Day.—Carried outfit across river in boat and began hole No. 1. Made 14 ft. in top soil and 11 ft. in gravel by 5 p. m.

*_Engineering-Contracting_, Jan. 6, 1909.

Second Day.—Finished hole No. 1, 2½ ft. more to bed rock, total 27½ ft. Pulled casing and began hole No. 2, 100 ft. distant before noon, and sunk the hole 17 ft. deep to bed rock before 4 p. m. Pulled casing and moved to hole No. 3, drilling 9 ft. in overburden.

Third Day.—Finished hole No. 3, 24 ft. deep. Pulled casing and started hole No. 3 by 2 p. m. Passed through 12 ft. of overburden and 10 ft. of sand and gravel by 5 p. m.

Fourth Day.—Finished hole No. 4, which was 28 ft. deep to bed rock. Pulled casing, cut trail and moved to hole No. 5, 300 ft. northeast of hole No. 4, and started new hole by noon. After drilling 17 ft. through overburden an old buried tree was struck, but the drill went through it easily. By 5 p. m. 22 ft. were made in this hole.

Fifth Day.—Finished hole No. 5, 28 ft., and after pulling casing began hole No. 6. Got down 14 ft. in overburden and 9 ft. in gravel by 5 p. m.

Sixth Day.—Finished hole No. 6, going down 9 ft. more to bed rock. Moved outfit across the river and about a mile up the river, and at 2:45 started hole No. 7. Made 6 ft. in overburden and 9 ft. in gravel by 5 p. m.

Seventh Day.—Finished hole No. 7, 29 ft., to bed rock, and moved 50 ft. north and sunk hole No. 8, 22 ft., to rock. Started hole No. 9, 50 ft. north, and made 6 ft. in top soil by 5 p. m.

Thus in seven days of drilling 213½ ft. were drilled, an average of 30½ ft. per day. It will be noticed that as the men became accustomed to the work, they improved a little each day.

With the Empire drill an auger drill spoon is used that will cut through hard soils, roots and sunken logs and easily penetrates gravel. It picks up any material and brings it as a core to the surface with a minimum amount of disturbance of the material as it actually lies in the ground. Water, as a rule, is not used to assist in drilling, so the auger will pick up the finest particles of gold. If it is desired to use water in drilling it can be done. The casing is pulled by levers with a very simple device.

With wages at $1 per day for the men the expenses were about $10 per day, allowing $1 for incidentals, the cost per foot was about 33 cts. With standard wages the cost per lin. ft. would have been about 47 cts.

Cost of Testing for Bridge Foundations.*—Mr. F. H. Bainbridge is author of the following:

This article is confined to bridge foundations, although much of what follows is also applicable to foundations for buildings and hydraulic structures and preliminary examination for tunnel construction.

Two methods of testing only are effective, an open pit or well for shallow foundations and the core drill for deep foundations. Sound-

---

**Engineering-Contracting*, Nov. 25, 1908, reprint from "Mine and Quarry."

ing with gas pipe or rods in shallow foundations and the common well drill in deep foundations are not satisfactory. Fig. 6 shows two cross-sections of a stream at the same point, the dotted line being the line of supposed ledge rock as determined by a well drill operating a chopping bit; and the full line, the correct location of the ledge rock, determined with a Sullivan "HN" diamond core drill.

In general two sets of borings should be made for an important bridge crossing; the first set, a number of borings on the center line of the proposed location, to determine whether the site is a favorable one, and, if favorable, to determine by approximate estimate the most economical location of the piers and the length of the spans. In a general way it may be assumed that the economical relation is reached when the cost of the substructure equals the cost of the superstructure; but inasmuch as the cost of the superstructure can be determined with considerable accuracy, while the cost of the substructure is involved in great uncertainty, the length of the spans selected should exceed that of the apparent economical relation. The length of spans chosen may also be influenced by other than economical considerations, such as government requirements, or the liability of ice to gorge against the bridge.

Having made a tentative location of the piers, borings should be made at each pier, and in the case of pneumatic or open dredged caisson foundations, one boring should be put down at each of the four corners of the caisson.

The preliminary borings may often be dispensed with when there are well records on both sides of the river in the vicinity. These well records can almost always be found in the various state geological reports, which can be had at any public library in the state. In case of the borings at Pierre, South Dakota, to be described later, the well records were so good that borings to determine the length of the spans were not necessary.

In cases where pile foundations are feasible and the river bottom is firm enough to lay concrete on, no borings are necessary, the required length of piling being best determined by driving experimental piles; but where the river bottom is soft, as it is in most streams with a sluggish or reversing current, borings should be made, the softer material being taken out dry with a sawtooth bit. This is feasible in the hardest clay or the softer shales and gives a perfect knowledge of the material encountered. Unless dry cores are taken when feasible, a hard clay in every way suitable for a foundation may be overlooked and provision made for carrying the foundation farther down than necessary.

In pneumatic work an accurate set of borings with a core drill is of incalculable value. These advantages are:

1st. The final location of the caisson can be accurately determined and cut stone and timber ordered without any waste or delay waiting for material for which no provision had been made.

2d. The contractor in bidding on the work knows exactly what material is to be encountered, and will make a lower bid when there

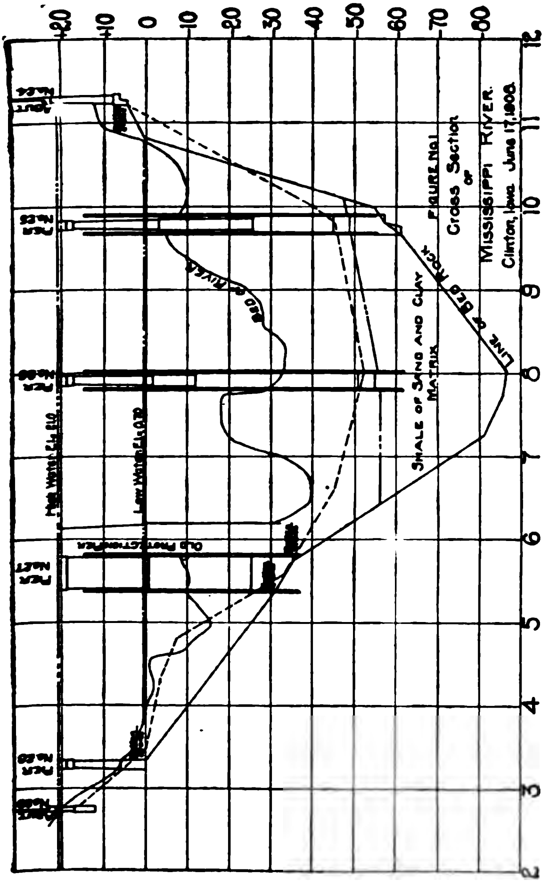


Fig. 6. Profile of Borings.

is no uncertainty. The difference in cost between handling in a caisson material which can be taken out through the blow pipe and material which must be locked out in buckets is very great.

3d. The piers can be located in the most economical position. Often a change of a few feet in locating a pier may make a difference in cost of tens of thousands of dollars.

4th. Much can be learned as to the character of the foundation that cannot be learned from the interior of the caisson. In limestone formations subterranean caverns are common, and in both lime and sandstone formations overhanging subterranean cliffs are found. The existence of these can be determined with the drill, but cannot be learned from the interior of the caisson.

Nearly the whole North American continent north of the Ohio River and east of the Missouri River has at various periods been covered with glacial drift; in fact, the Ohio and Missouri Rivers were formed by glacial action. Below the recent alluvial deposits in a riverbed in this district will be found glacial deposits of sand, gravel, clay, till, or boulders, sometimes all together in a heterogeneous mass. The extreme determined movement of the greatest glacial sheet was 1,500 miles. Boulders of granite from Canada and Minnesota were carried as far as Kansas and Missouri. One of the boulders in the river bed is therefore liable to be mistaken for ledge rock. Usually the character of the ledge rock can be learned from state surveys and samples secured from the outcrops, which are located in these surveys. When a core is obtained which can be identified as the same as ledge rock it may or may not be the actual ledge. If the core is granite or some older formation than the ledge rock, it is certain that a boulder has been reached. More recent rocks sometimes exist as pockets in earlier formations, so that a mere difference in the character of the rock from the bed rock is not conclusive evidence that bed rock has not been reached. When such a condition is liable to be found in any locality it will usually be mentioned in the state geological surveys. Boulders of granite and other hard rocks must be removed by placing sticks of dynamite at the bottom of the stand-pipe, withdrawing the pipe, and exploding with an electric battery. Boulders of softer rock can be cut up with the chopping bits and the casing driven through them. As boulders are usually separated by a matrix of sand or clay, the drop of the rods and the wash will show them as boulders and not bedrock in most cases, though this is not always conclusive, as pockets sometimes filled with sand are common in limestone ledges.

No definite rules can be given to cover all cases, and it is best, especially where there is any uncertainty, to put down a hole at each of the four corners of a pier. Where the drill strikes first rotten or sap rock, gradually increasing in hardness until known ledge rock is reached, this is conclusive evidence of bed rock. It is best to take out very soft, rotten rock with a saw tooth bit working dry.

Drill tests for foundations of the Chicago and Northwestern Rail-

way bridge across the Missouri River at Pierre, South Dakota, were begun in December, 1905. The drill used was a Sullivan Machinery Company's "HN" diamond drill, operating 2-in. core bits; 4½-in. stand-pipe and 3-in. casing, both with flush joints, were used. Borings at the sites of the river piers were made from the ice. In general four holes were put down at the site of each pier. On diagonally opposite corners holes were put down to about 90 ft. below low water, and on the other two corners to 60 ft. below low water. Thirty-three holes in all were put down, aggregating a length below the river bed or ground level of 2,379 ft., of which 1,456 ft. was in sand, gravel, and boulders, and 828 ft. in shale, with occasional small lenticular pieces of limestone. On the east or left bank heavy beds of glacial drifts were encountered and there was some difficulty in putting down stand-pipe and casing. The boulders were broken up with dynamite. In shale, saw tooth bits were used entirely, the bortz bit being used only in the limestone pockets.

The work of setting up the drill was started December 5, 1905, and the first boring started December 8, 1905, with one shift working 10 hours. On January 17, 1906, a second shift working 10 hours was put on.

Shale was found practically level over the entire cross-section at 42 ft. below water. There was apprehension upon encountering an underground flow of water in the upper strata of the shale, but in no case was this more than a few feet below the top of the shale.

Caissons for the permanent piers penetrated the shale from 4 to 6 ft. and the material encountered was accurately described in the record of the borings. The cost of the drilling, including 10 per cent for depreciation of plant and tools, was about $2,400, or about $1 per ft.

In 1908 the Northwestern Railway began tests to locate suitable foundations for a new bridge over the Mississippi River at Clinton, Iowa. The same apparatus, tools, piping, etc., were used at Pierre, but the manner of working and the materials encountered were essentially different. These borings were started in April, and it became necessary to mount the drill on a scow. The scow was 15 ft. wide, 32 ft. long on the bottom and 37 ft. long on top, with a draft of 16 ins. when loaded. Experience in rough water showed that a scow 10 ft. longer on top with somewhat more rake to the ends would have been more serviceable. The tripod consisted of three pieces of Douglas fir, 5x8 ins. and 32 ft. long. An 8-in. wrought iron pipe near the center of the scow, bolted with a pipe flange to the bottom of the scow, made a well for passing the stand-pipe, 4½ ins. in diameter, and the casing, 3 ins. in diameter.

The materials encountered were in order as follows: Recent alluvial sands, glacial drift of gravel, sand and boulders, a shale consisting of sand with a clay matrix, and finally limestone bed rock. The upper stratum of bed rock was identified by fossils and general appearance as belonging to the Gower stage of the Niagara

series of Silurian rocks. This overlaid conformably rock of the Delaware stage of the same series. In the middle of the river the Gower rock and nearly 50 ft. of the Delaware rock had been entirely eroded. Great care was taken to ascertain the possible existence of subterranean pockets or overhanging cliffs in the rock. Only two of these pockets were found, however, both in the same boring, and these were only 1 and 6 ins. in depth. Both were filled with sand, consisting of about equal parts of quartz and dolomite sand. Some of the borings were carried down 30 to 40 ft. into the bed rock to determine the possible existence of these subterranean pockets.

All the boulders encountered were such as could easily be broken with the chopping bit and no dynamite was found necessary. To determine the consistency of the shale, cores were taken out with saw tooth bits working dry, showing perfectly the consistency of the material. The saw tooth bit or the chopping bit working with the pump gave no idea of what this material was, and without the expediency of the dry core an excellent foundation would have been overlooked, and a foundation sought 30 ft. lower. It is intended to use pneumatic caissons in all the piers except the shore piers.

Borings in the limestone were made with a bortz bit when the water was still, and with the chopping bit taking occasional cores with the saw tooth bits. Fully 95 per cent of the boring in the limestone was made with the bortz bit. The work of mounting the drill was started April 2 and the first hole begun April 7. The work was finished June 6, working one shift of 10 hrs. per day.

The aggregate length of casing put down was 692 ft. The aggregate length of casing driven through hard material was 406.5 ft. The aggregate length of borings in shale was 86 ft., and in limestone 226 ft. The cost was as follows:

Labor	$ 456.16
Coal	124.41
Depreciation of bortz, estimated	200.00
Scow	287.24
Depreciation on tools, pipe, etc.	200.00
	$1,267.81

The scow still has a value which is somewhat uncertain. Omitting this credit, the cost amounted to $1.83 per ft.

Costs of Making Test Borings, Ill., Etc.*—Despite the wide use of test borings few engineers or contractors seem to have taken the trouble to amass data on the cost of making them, at least few such data can be found in print. The records which we give here are from scattered sources and are less complete than could be wished, but in default of better, they are of interest.

The several prices of work of which costs are given were done with a No. 80 Pierce tubular well and test boring rig. This machine consists of a base on which sets four uprights serving as guides for the driving hammers and the pipe. In operation the base is set up

***Engineering-Contracting*, Dec. 26. 1906.

level and the hammer is set on it. The four guides are then fastened in position. The whole machine is then laid over sidewise on the ground, the head casting is placed and the hoisting cable is connected up. The assembled machine is then lifted to a vertical position and is ready for work. The first section of pipe with the steel cutting shoe attached is then put in position by raising the hammer and attaching the pipe guide clamps. The pipe is then driven by raising and dropping the hammer exactly as in driving a pile. The pipe being driven, the upper part of the machine is slid rearward on the base so as to clear the pipe and a 2-in. discharge tee is screwed to the tap of the pipe. The drill with water discharge holes near the bottom and the hollow drill rod are inserted in the pipe and the top of the drill rod is connected by hose to a hand pump. One man then pumps water down the hollow drill rod while another churns the drill up and down to chip and loosen the material which is carried upward through the annular space between pipe and rod and discharged into a pail so that samples can be taken. A second joint of pipe is then screwed on and driven and the drilling and working out process is repeated. In this way by alternate drilling and driving the boring is carried to the required depth. The next step is to take out the pipe so that it can be used for a second hole; this is accomplished by means of a screw jack apparatus. With the No. 80 machine a 2-in. pipe in 5 ft. sections is used. The limit of drilling of this rig is considered to be about 125 ft., for deeper holes a heavier rig is employed.

Illinois and Desplaines Rivers Survey.—In making surveys, plans and estimates for a 14-ft. waterway from Lockport, Ill., by the Desplaines, Illinois and Mississippi rivers to St. Louis, Mo., test borings were made along the route. From the official report of this work submitted to the U. S. Government and from additional data sent us by Mr. J. W. Woerman, of Peoria, Ill., who was Assistant Engineer in charge of the work from Lockport, Ill., to the mouth of the Illinois River, we have prepared the following description of the test boring work.

On one of the quarter boats a well was cut through the rake at one end through which to operate the boring machine. A 10x 10-in. x 32 ft. spud was provided at each corner of the boat to hold it fast while drilling. An office and living quarters for the crew and a blacksmith shop were installed on the boat. The machine used to make the borings was a "Pierce test boring rig No. 80." It consisted essentially of a 2-in. outer pipe, or casing, and ¾-in. inner pipe or drill, with arrangements for forcing them into the ground. Water was forced down the smaller pipe, and came up again between the two pipes, carrying with it, in suspension, the material from the bottom of the river. The casing was made of extra strong wrought iron pipe, screwed together in 5-ft. lengths as it was driven down by a 200-lb. hammer. The hammer had a maximum fall of 8 ft., and was kept in line over the casing by four iron guides. It was raised with a small hand winch. The drill was made of light wrought iron pipe, to the top of which was attached a 1¼-in. hose connected with a steam deck pump on the towboat.

A hand pump, furnished with the boring machine, was used only when it was necessary to send the towboat away from the boring boat. The drill was churned up and down by hand, when the outer casing was not being driven, and the material which came up between the two pipes escaped through a tee connection at the top of the large pipe. Samples were taken frequently by catching portions of this mixture in pails and allowing it to settle. In order to make the casing drive easily the drill was kept from 3 to 5 ft. in advance of the casing, and any change in material was noted as the drill entered it.

The borings were made in or near the channel, to a depth of about 30 ft. below low water. This was done because, when the boring boat was anchored and the machine was in operation, it cost but very little more to go 30 ft. than to stop at the proposed depth of 14 ft., and the additional information may prove valuable at some future time. As a rule the borings were spaced about half a mile apart, but if rock was encountered, or if there was any other decided change in the character of the bottom, the holes were placed close enough together to define the limits of the material. The work of making borings in the river bed was completed on July 2, 1904, and the party disbanded.

The materials penetrated were mud, sand, gravel, clay, shells, soapstone, coal and various mixtures of the above materials. When the boring reached bed rock it was necessary to stop. Bed rock was not struck very often, however, and when it was, additional borings were made in the vicinity to be sure that the drill was not in a boulder instead.

The boring party consisted of ten men who were furnished with quarters and subsistence which cost about $15 per month per man. The wages paid the members of the party were as follows:

	Rate per month.
1 civil engineer in charge	$125.00
1 pilot	75.00
1 steam engineer	75.00
1 fireman	50.00
1 cook	50.00
1 blacksmith	45.00
1 night watchman	35.00
3 laborers, at $35.00	105.00
10 men	$560.00

In addition to the above wages there were also charged against the work various other expenses as indicated in the following paragraph from the official report:

"The cost of subsistence, while the men were on the quarter boats, has been charged to the various parties, according to the number of men in each party. When parties boarded away from the quarter boats, the amounts of their board bills were charged directly to that branch of the work upon which they were then engaged. The cost of the construction and equipment of the quarter boats, the cost of instruments, tools, office furniture, etc., was also charged pro rata to the various branches of the work. This was

done in order to make the total cost agree with the actual amount expended on the survey, but as this is not done usually, it should be taken into account in making comparisons with the cost of any other surveys. These items amounted to about $18,000, or more than one-tenth of the total amount expended. These articles are all in good condition and will give good service for many years to come. The cost figures given also include a portion of the expenses of the Chicago office, as well as all expenses connected with the Peoria office."

With all the above charges included the cost of making test borings on this survey was:

Total cost	$7,797.00
Cost, per hole	13.70
Cost, per lin. ft. of hole	0.62

Erie R. R.—A record of four weeks' work, Nov. 7 to Nov. 28, inclusive, on the Erie R. R., gives the following figures:

Superintendent, 18 half days, at $5	$ 45.00
Foreman, 19 days, at $2.50	47.50
Laborers, 41 days, at $2.00	82.00
Total	$174.50

The total depth of hole bored was 699.1 ft. The labor cost of making the borings was, therefore, 24.9 cts. per lineal foot of hole. The holes were bored through sandy red clay.

New York Central & Hudson River R. R.—Two test borings were made 90 ft. deep in one day in February, 1905, for some work being done by the New York Central & Hudson River R. R. The borings were made in one case through 3 ft. of frozen ground and in the other case through 3 ft. of ice, moving the machine 600 ft. from one hole to the other. Both borings were made in one day at a total labor cost of $5 or 2½ cts. per lineal foot of hole.

Cost of Test Borings with Wood Augers.*—Mr. A. C. D. Blanchard is author of the following:

The borings enumerated below were made in the city of Toronto during the last year in order to find the character of the soil to a depth of from 30 to 70 ft. These borings were made in connection with several works which were about to be built, and were taken in different parts of the city. The ground met with consisted chiefly of blue clay, although seven borings were made in wet, sandy clay, and four were made in filled ground. The average length of holes is shown for each locality. The borings were all made with a 1½-in. carpenter's machine auger, welded to the end of a ¾-in. pipe. The ¾-in. pipe was cut in sections 6 ft. long, and each length was added as it became necessary.

In the process of boring the auger was turned by two or three men with Stillson wrenches, at the surface. The heavier clay required three men to turn the auger. After the auger had bored from 8 to 12 ins. it had to be removed from the hole and cleaned

*A paper in *Engineering-Contracting*, Aug. 11, 1909, reprinted from "The Canadian Engineer."

and then replaced in the hole, and continued for another auger length. Considerable time was thus lost in having to remove the auger and getting it back to its position again, especially after the hole became quite deep. Samples were taken from each boring and bottled.

The force consisted of one recorder and three laborers each at $2 a day. The work was done at all seasons of the year, and no time was lost by any of the men. The cost of blacksmith work and teaming amounted to about 5 per cent of the total cost, and the cost of material, such as augers, wrenches and iron pipe, amounted to about 10 per cent. The following is a statement of the itemized cost of the work:

(1) HEAVY BLUE CLAY: 10 INS. OF RED CLAY ON TOP.

Number of holes		28
Total depth, ft.		709
Average depth of hole, ft.		25.3
Cost.	Total.	Per ft.
Labor	$199	$0.281
Materials and blacksmith	34	0.048
Total	$233	$0.329

(2) MADE GROUND.

Number of holes		4
Total depth, ft.		90
Average depth of hole, ft.		22.5
Cost.	Total.	Per ft.
Labor	$ 44	$0.488
Materials and blacksmith	5	0.066
Total	$ 49	$0.554

(3) FINE, RUNNING, CLAYEY SAND.

Number of holes		36
Total depth, ft.		1,163
Average depth of hole, ft.		32.3
Cost.	Total.	Per ft.
Labor	$293	$0.252
Materials and blacksmith	43	0.037
Total	$336	$0.289

(4) HEAVY CLAY.

Number of holes		7
Total depth, ft.		152
Average depth of hole, ft.		21.7
Cost.	Total.	Per ft.
Labor	$ 48	$0.315
Materials and blacksmith	9	0.059
Total	$ 57	$0.347

(5) HEAVY BLUE CLAY.

Number of holes		5
Total depth, ft.		160
Average depth of holes		32
Cost.	Total.	Per ft.
Labor	$ 40	$0.250
Materials and blacksmith	6	0.038
Total	$ 46	$0.288

Cost of Drilling Test Holes with a Well Driller.*—This drilling was done with a Star drilling machine (well drilling type) to test the site of a double track, steel trestle for concrete pedestal foundations. Seven holes were put down for a total depth of 190 ft. through clay and gravel to solid rock. The average depth of soil was 23 ft. and the average penetration into rock was 4 ft. The actual time consumed in drilling and moving from one hole to another was 11½ days and the total distance over which the drill was moved was 730 ft. The average time per foot of hole drilled, including moving, was 30 mins. The contractor furnished the drill and labor at cost plus 10 per cent on labor, and his bill was as follows:

	Rate.	Total.	Ft.
Driller, 11½ days	$3.50	$40.25	$0.212
Helper, 11½ days	1.75	20.13	.106
Teaming, 2.1 days	4.00	8.10	.044
Labor, 10 days	1.75	17.50	.092
Use of drill, 11½ days	2.00	23.00	.121
Coal, 45 bushels	.08	3.60	.018
4⅝-in. casing, 54⅝ ft.	.35	19.13	.100
Teaming 1 day for other parties	..	4.00	.021
10% for supt. and use of tools as above	..	8.63	.046
Total		$144.64	$0.760

The above cost does not include any charge for inspection, as the regular inspector for the railroad company had to be on the ground to watch other work and could easily keep track of the drilling. For the above information we are indebted to H. M. Chapin, Resident Engineer, F. & C. R. R.

Cost of Diamond Drilling, Cross-References.—The foregoing data relate to costs of test borings through earth. For similar test borings in rock, see the section on Rock Excavation, under Diamond Drilling.

Cost of Sinking a Well.†—Mr. Daniel J. Hauer is author of the following:

The well was driven in a rolling country, where rock does not occur. The materials through which it was sunk were stiff red clay and sand. A tidewater marsh adjoining the site of the well furnished a poor quality of water to start the sinking of the drill, the hydraulic method being used. All remarks made by the writer will be regarding driven wells. The distinction being made from open wells, large enough for a man to enter.

These machines are generally mounted on wheels, with a mast on one end. This mast is jointed about 6 ft. from the base, so as to admit of it being lowered on to the bed of the machine, when it is necessary to move from one job to another. When the machine is in use the mast is upright and is guyed and held in place by two brace rods or timbers bolted to it near the top. The bit used on such a machine is solid and "the string of tools" consisted of rods, one end being a socket and the other a bolt end, all

**Engineering-Contracting,* Mar. 4. 1908.

†*Engineering-Contracting,* May 23, 1906.

threaded. The top piece has a "rope socket" on the upper end, used to attach it to the machine. With such a well boring apparatus, the hole must be cleaned when a depth of from 2 ft. to 5 ft. has been obtained. This necessitates removing the boring tools and pumping out the debris or "sludge" with a sand pump, all of which consumes a large amount of time, especially if the well is driven to a depth greater than 100 ft. The hydraulic method of driving wells obviates the use of the sand pump, and in wells of any depth, through soft material, is preferable to the other method.

Driven wells are usually from 6 ins. to 16 ins. in diameter. A hole less than 6 ins. cannot be driven to any great depth as the tools would have to be so light as to run grave chances of breaking them. Fifteen and sixteen-inch holes are the maximum at present, owing to the fact that these seem to be the sizes of the pipes for casing, that are made economically and are easily placed in the well. Many manufacturing plants are using twelve and fourteen-inch wells.

When the hydraulic method is used a square pyramidal derrick from 40 ft. to 70 ft. in height is erected. Timber is used for these structures by well drilling contractors, but the writer sees no reason why a tower, modeled after those used by prospectors in taking ore drillings, and made of steel, could not be used and taken down after each job and moved to a new site. Of course, the timber can be used more than once, but each time some of it is used up and all of it has to be renewed after several jobs. The life of a steel derrick, if kept painted, would be many years, and only the bolts would have to be renewed from time to time. The tools differ somewhat from those previously described. The bit is hollow, with a hole just above the cutting point on either side to allow the jet of water to enter the well. Instead of rods, pipes are used, and the rope socket has an attachment to which is fastened the hose, run from the pump to the drilling column.

The well in this case was 8 ins. in diameter. The derrick was 50 ft. high. The first deck was 20 ft., while the three upper decks were each 10 ft. The head blocks carried a sheave. On one side of the derrick was a ladder. On the other side was fastened the windlass and gearing. The corner posts of the derrick were 4 x 6 in. timbers, while the braces were 2 x 8 in. and 1 x 12 in. planks; the head blocks were 4 x 6. Twenty-five hundred feet board measure of timber was used for the derrick and about 500 ft for a tool house and other needs. The outfit consisted of the following: An upright boiler and engine on separate bases, a steam duplex pump, two hand pumps, windlass and gearing, two hammers for driving well casing, ropes and blocks, drill points, hard rubber hose, wrenches of various kinds, pipe cutters and dies, and various small tools. Several tents for the workmen to live in while driving the well, and bedding and cooking utensils were also included in the outfit. The approximate value of this outfit, when new, was $2,000. Allowing 25 per cent per year for interest and depreciation, and considering 100 work days as covering a season's work for an out-

fit, we have a daily plant charge of $5.00. This is small considering the hard usage the plant undergoes. The boiler has all kinds of water used in it, which quickly injures the tubes. The pumps also fare roughly from the pumping of water saturated with the debris from the well, the water being used over and over again. The continual handling of the pipe soon wears out the threads, necessitating cutting and making new threads, and so it is with other details of the outfit, all of which quickly takes money for renewals and repairs. As a large percentage of wells are driven in inaccessible parts of the country, a well driving contractor must carry with him every tool that any emergency may demand.

In the work which the writer is describing five days were consumed by two men in erecting the derrick and setting up the plant. Then a length of 12-in. pipe was sunk to protect the mouth of the well, after which the well driving commenced. As stated above, water to start the work was used from an adjoining swamp. The first day's driving resulted in a depth of over 50 ft. and gave enough water to continue the work. The average depth obtained each day of actual driving was 20 ft., but the average for the total time consumed in working on the well was a fraction over 11 ft. The well was sunk to a depth of 339½ ft., when sufficient water was obtained to fulfil the terms of the contract. At 260 ft. a stratum of sand was struck and the well was cased up and tested, but as the vein of sand was not over 3 ft., it did not give sufficient water and the driving was continued. At a depth of 318 ft. sand was again encountered, and again the well was cased up and the strainer put in place and the well tested, the strainer being located at the depth given above. No effort was made to obtain the depth of this stratum of water bearing sand.

Seventeen days were consumed in driving the well, and five days in casing up, placing the strainer and testing. One day sufficed to dismantle the plant and haul it away. As the outfit was on the road two days, two additional days are included in the plant charge. Three and one-half tons of coal were used, there being a daily consumption of 320 lbs. The cost of this, including hauling, was $5.25.

The crew consisted of one experienced drill driver, who acted as foreman when the contractor was absent, and two laborers, both of whom had had some experience in driving artesian wells. The derrick was built and the machinery placed by the foreman and one laborer, the second laborer coming on the work only after the well driving began. At all critical stages of the work a member of the contracting firm took charge of the forces and worked with the rest of the crew, doing whatever came to hand. In all he worked in this manner seven days. In the record of cost given an allowance of $3.50 is made for each of these days' work. The rates of wages or their equivalent for the other men were as follows:

Well driver	$2.75
Laborers	2.00

The wages were paid weekly and included board; but the figures

given show the daily cost for ten hours' work to the contractor, made up from a season's employment. All of the men were paid full time, and frequently were called to make over-time without additional pay. Well driving can be done during wet weather without serious inconvenience to the men, as they seldom stop except in steady downpours of rain. This is made possible by only a few men being employed; with a large number, a few become dissatisfied and the whole force is stopped.

The itemized cost of the well, for both labor and materials, except the strainer, was as follows:

Labor:	
Erecting derrick and machinery	$ 23.75
Driving well and casing	170.75
Pumping and testing well	12.25
Tearing down derrick, etc.	6.75
Total labor	$213.50
Materials:	
3½ tons of coal, at $5.25	$18.37
Pipe casing, 340 ft., at $0.86	292.40
Outer casing (second hand)	10.00
Derrick timber, 3,000 ft. B. M., at $25.00	75.00
Total materials	$395.77
Miscellaneous:	
Transportation charges	$100.00
Plant rental, 30 days, at $5.00	150.00
Superintendence and general expenses	50.00
Total miscellaneous	$300.00
Grand total	$909.27

The transportation charge is for both freight by train and hauling by wagons to and from the job, and is a little higher than usual. The figures giving a cost per lineal foot of well are as follows:

Labor	$0.63
Materials	1.16
Miscellaneous	0.88
Total	$2.67

It is of interest to note that the cost of fuel, which is high per ton, amounts to a fraction over 5 cts. per foot of driven well, which is a comparatively small cost. The full charge is made against this job for the derrick timber, although some of it had been used previously and all of it was hauled away to be used on another job.

The boiler was fired by the man attending to the pumps or else the man running the windlass. The consumption of coal might have been reduced somewhat by the boiler having a cheap house over it and the steam pipes being covered. On a single job like this but little saving would be shown, but in a year or two the additional cost would be more than saved. With a small boiler a house could be constructed readily in sections and moved from job to job. The steam pipes could also be lagged and handled in the same manner. The writer feels confident that these are details well

worth considering not only in well driving, but also on much other construction work.

The contractor doing this work owns three such outfits, and in spite of the fact that three or four men can operate each plant, he states that it is exceedingly difficult to obtain men to put in charge of a plant; men who can be relied upon to face any crisis in the work and handle it without a money loss. For these reasons he seldom runs but two machines, as he can give these his personal attention and only keeps the third plant for an emergency. That is, to take a job from an old customer, that may go to a competitor, or land new work that is exceedingly desirable. Margins are so close that a single mistake of judgment may use up the entire profit of a job.

After pumping this well, the sinking of which has just been described, for 24 hours the flow was tested and found to be 66 gallons per minute. The water level had only been reduced 20 ft. by this pumping. The strainer was placed 340 ft. below the level of the ground, the elevation of the latter being 5 ft. above mean low tide. The strainer used was made from a piece of pipe plugged at one end and punched with holes, the dimensions of which were ½ in. x ⅝ in.

The placing of the strainer and the variety of strainer used is a matter of vast importance and every detail regarding it should be specifically stated in a contract for a driven well. All too frequently this is not done, and the entire matter is left in the hands of the contractor, who only sees that the well comes up to the required tests and that a strainer is properly placed in the well. The kind he will use will be the style he is accustomed to, which may not be suitable for the well in question.

Strainers, of which there are a number of styles patented and used, may be classed as either fine or coarse. The majority of the older patents are for fine strainers, that is, the openings are made so small as to admit of water entering the pipe and yet stop the finest sand. The slots are cut larger on the inside than on the outside of the pipe, so as to allow any grains of sand that may enter the opening to go into the strainer and not clog the hole. The openings in fine strainers are less than 1/50 in. in size. It is evident that with little corrosion or rust these holes will become closed and the entire well rendered useless. In the coarse strainers this will neither happen as often or as soon, hence they are preferable. The main objection to this class of strainers is that they will gradually fill with sand and thus stop the flow. This can be obviated. If the grains of sand were of equal size in water bearing sand, we would only need to have openings of such a size as to not admit the grains and the difficulty would be solved, but as a rule the grains of water bearing sand not only vary greatly in size, but also contain some gravel.

When gravel is not carried by the sand some should be placed around the strainer by artificial means. Then the well should be pumped at a rapid rate for such a length of time as may be neces-

sary to draw in all the fine sand that may ultimately be disturbed by the velocity of the water. When this is done and the sand cleaned out of the well, and the coarse strainer properly placed, no trouble should occur from this source. At times it may be found necessary to use air pressure to agitate the fine sand, as the pumping is going on, so as to facilitate the drawing in of the fine particles. Trouble will only occur when the inflow of water is of such velocity as to carry the fine fluid with it.

These operations are rather costly and it cannot be expected that the contractor will do them, unless they have been previously specified, so that his price is made to cover them. The engineer should see to this. Many wells that have to be reworked only needed these things done when they were driven. The costs that have been given do not include any work of this nature.

(For further data on well driving, see the index under Wells.)

References and Cross-References on Earthwork.—For cost data on dredging, hydraulicking earth, and costs by many other methods of excavation, the reader is referred to my book on earthwork. In various sections of this book will be found other data on earthwork costs, for which consult the index under "Excavation, Earth."

SECTION III.

ROCK EXCAVATION, QUARRYING AND CRUSHING.

Weight and Voids.—Civil engineers commonly measure rock excavation by the cubic yard in place before loosening, whereas mining engineers generally use the ton of 2,000 pounds as the unit of rock and ore measurement. In view of this fact it would be well were the specific gravity of the rock given by every engineer who publishes data on any particular kind of rock excavation or mining. Then, too, it often happens that broken rock is purchased by the ton even for civil engineering work, or by the cord of loosely piled rubble for architectural work, thus emphasizing the importance of stating not only the specific gravity but the percentage of voids.

The specific gravity of any material is the quotient found by dividing its weight by the weight of an equal bulk of water. Water, therefore, has a specific gravity of 1; a cubic foot of any substance like granite, having a specific gravity of 2.65, weighs 2.65 times as much as a cubic foot of water. A cubic foot of water weighs 62.355 lbs., or practically 62.4 lbs.; hence a cubic foot of solid granite weighs, $62.4 \times 2.65 = 165.3$ lbs.

When any rock is crushed or broken into fragments of tolerably uniform size it increases in bulk, and is found to have 35% to 55% voids or inter-spaces, depending upon the uniformity of the fragments and their angularity. Rounded fragments, like pebbles, pack more closely together than sharp-edged or angular fragments. A tumbler full of bird shot has about 36% voids, and it is possible to hand-pack marbles of uniform size so that the voids are only 26%. Obviously, if small fragments of stone are mixed with large fragments, the voids are reduced. Pit sand ordinarily has 35% to 40% voids. Hard broken stone from a rock crusher has about 35% voids if all sizes are mixed and slightly shaken down in a box; whereas, if it is screened into several sizes, each size has about 45% to 48% voids.

A soft and friable rock like shale breaks into fragments having a great range in size, from large chunks down to dust; and, as a consequence, such soft broken rocks have a much lower percentage of voids than the tougher rocks.

The following table shows the swelling of rock upon breaking:

Voids	30%	35%	40%	45%	50%	55%
Cu. yds. broken rock from 1 cu. yd. solid rock....	1.43	1.54	1.67	1.82	2.00	2.22

TABLE III.

Specific Gravity.	Weight in Lbs. per cu. ft.	Weight in Lbs. per cu. yd.	Weight in Lbs. per cu. yd. when Voids are 30%	35%	40%	45%	50%
1.0	62.355	1,684	1,178	1,094	1,010	926	842
2.0	124.7	3,367	2,357	2,187	2,020	1,852	1,684
2.1	130.9	3,536	2,475	2,298	2,121	1,945	1,768
2.2	137.2	3,704	2,593	2,408	2,222	2,037	1,852
2.3	143.4	3,872	2,711	2,517	2,323	2,130	1,936
2.4	149.7	4,041	2,828	2,626	2,424	2,222	2,020
2.5	155.9	4,209	2,946	2,736	2,525	2,315	2,105
2.6	162.1	4,377	3,064	2,845	2,626	2,408	2,189
2.7	168.4	4,546	3,182	2,955	2,727	2,500	2,273
2.8	174.6	4,714	3,300	3,064	2,828	2,593	2,357
2.9	180.9	4,882	3,418	3,174	2,929	2,685	2,441
3.0	187.1	5,051	3,536	3,283	3,030	2,778	2,526
3.1	193.3	5,219	3,653	3,392	3,131	2,871	2,609
3.2	199.5	5,388	3,771	3,502	3,232	2,963	2,694
3.3	205.8	5,556	3,889	3,611	3,333	3,056	2,778
3.4	212.0	5,724	4,007	3,721	3,434	3,148	2,862
3.5	218.3	5,893	4,125	3,830	3,535	3,241	2,947

TABLE IV.—VOIDS IN LOOSE BROKEN STONE.

Authority.	Per cent Voids.	Remarks.
Sabin	49.0	Limestone, crusher run after screening out ⅛-in. and under.
Sabin	44.0	Limestone (1 part screenings mixed with 6 parts broken stone).
Wm. M. Black	46.5	Screened and washed, 2 ins. and under.
J. J. R. Croes	47.5	Gneiss, after screening out ¼-in. and under.
S. B. Newberry	47.0	Chiefly about egg size.
H. P. Boardman	39 to 42	Chicago limestone, crusher run.
H. P. Boardman	48 to 52	Chicago limestone, screened into sizes.
Wm. M. Hall	48.0	Green River limestone, 2½ ins. and smaller, dust screened out.
Wm. M. Hall	50.0	Hudson River trap, 2½ ins. and smaller, dust screened out.
Wm. B. Fuller	47.6	New Jersey trap, crusher run, 1/6 to 2.1 in.
Geo. A. Kimball	49.5	Roxbury conglomerate, ½ to 2½ ins.
Myron S. Falk	48.0	Limestone, ½ to 3 ins.
W. H. Henby	43.0	Limestone, 2-in. size.
W. H. Henby	46.0	Limestone, 1½-in. size.
Feret	53.4	Stone, 1.6 to 2.4 ins.
Feret	51.7	Stone, 0.8 to 1.6 in.
Feret	52.1	Stone, 0.4 to 0.8 in.
A. W. Dow	45.3	Bluestone, 89% being 1½ to 2½ ins.
A. W. Dow	45.3	Bluestone, 90% being 1/6 to 1½ in.
Taylor and Thompson	54.5	Trap, hard, 1 to 2½ ins.
Taylor and Thompson	54.5	Trap, hard, ½ to 1 in.
Taylor and Thompson	45.0	Trap, hard, 0 to 2½ ins.
Taylor and Thompson	51.2	Trap, soft, ¾ to 2 ins.
G. W. Chandler	40.0	Canton, Ill.
Emile Low	39.0	Buffalo limestone, crusher run, dust in.
C. M. Saville	46.0	Crushed cobblestone, screened into sizes.
I. O. Baker	43 to 47	Crushed limestone in sizes.
A. N. Johnson	41 to 51	Crushed limestone in sizes.
W. E. McClintock	47.0	Crushed trap.

The following records of actual tests will indicate the range of void percentages:

Prof. S. B. Newberry gives the voids in Sandusky Bay gravel, ¼ to ⅛-in. size, as being 42.4% voids; ¼ to 1/20-in. size, 35.9% voids.

Mr. William M. Hall, M. Am. Soc. C. E., gives the following tests on mixtures of Green River, Ky., blue limestone and Ohio River washed gravel:

Stone.		Gravel.	Voids in Mixture.
100%	with	0%	48%
80	"	20	44
70	"	30	41
60	"	40	38½
50	"	50	36
0	"	100	35

The stone passed a 2½-in. screen and the dust was removed by a fine screen. The gravel passed a 1½-in. screen.

The voids in mixtures of Hudson River trap rock and clean gravel, of the sizes just given for the Kentucky materials, were as follows:

Trap.		Gravel.	Voids in Mixture.
100%	with	0%	50%
60	"	40	38¼
50	"	50	36
0	"	100	35

Mr. H. von Schon gives tests on a gravel having 34.1% voids as follows:

	Per cent.
Retained on 1-in. ring	10.70
Retained on ⅝-in. ring	23.65
Retained on No. 4 sieve	8.70
Retained on No. 10 sieve	17.14
Retained on No. 20 sieve	21.76
Retained on No. 30 sieve	6.49
Retained on No. 40 sieve	5.96
Passed No. 40 sieve	5.59
Passed 1½-in. ring	100.00

Feret gives the following results of tests on mixtures of different sizes of pebbles, and mixtures of different sizes of stone (the stone and pebbles were not mixed together):

				——Voids in——	
Passing a ring of...	2.4″	1.6″	0.8″	Round	Broken
Held by a ring......	1.6″	0.8″	0.4″	Pebbles.	Stone.
Parts	1	0	0	40.0%	53.4%
"	0	1	0	38.8	51.7
"	0	0	1	41.7	52.1
"	1	1	0	35.8	50.5
"	1	0	1	35.6	47.1
"	0	1	1	37.9	49.5
"	1	1	1	35.5	47.8
"	4	1	1	34.5	49.2
"	1	4	1	36.6	49.4
"	1	1	4	38.1	48.6
"	8	0	2	34.1	

Mr. A. W. Dow gives the following tests on mixtures of broken stone and gravel at Washington, D. C.:

—Parts of Broken Bluestone—			—Parts of Gravel—		
Granolithic (92% being 1/10 to ⅛")	Coarse (89% being ½ to 2½")	Average (90% being ⅛ to 2")	Average (90% being 1/6 to 1½")	Small (90% being ⅛ to ⅝")	Voids. Per cent.
....	1	....	....	....	45.3
....	....	1	....	....	45.3
1	....	1	....	....	39.5
....	....	....	1	....	29.3
....	....	1	....	1	35.5
....	....	2	....	1	36.7

Taylor and Thompson give the following:

Ref. No.	Stone.	Size.	Voids in loose stone.	Per cent Compression by light ramming or shaking.	Per cent Voids after light ramming.	Per cent Compression by heavy ramming.	Per cent Voids after heavy ramming.
1....	Hard trap	2½" to 1"	54.5	....	....	19.2	43.7
2....	Hard trap	1" to ½"	54.5	14.3	46.9	20.5	42.8
3....	Hard trap	2½" to O	45.0	14.5	35.7	20.8	30.6
4....	Soft trap	2" to ¾"	51.2	11.9	44.6	17.8	40.6
5....	Soft trap	¾" to ⅜"	51.2	14.3	43.1	23.9	35.9
6....	Gravel	2½" to ½"	36.5	12.5	27.4	11.5	28.2

The stone was thrown into a measuring box and measured, then rammed in 6-in. layers. The variation in the last column for Nos. 4 and 5 was due to the breaking of the trap under the rammer. No. 3 was "crusher run" containing 44.4% of No. 1, 33.3% of No. 2, and 22% of screenings from ½-in. down to dust. Nos. 1, 2 and 3 were crushed in a gyratory crusher; Nos. 4 and 5, in a jaw crusher.

Mr. George W. Rafter gives the voids in clean limestone, broken (by hand?) to pass a 2½-in. ring, as 43% after being "slightly shaken," and 37½% after being rammed.

Mr. Desmond FitzGerald states that broken stone dropped 12 ft. into a car measured 7% less in volume after the fall.

As originally pointed out in my "Rock Excavation," I have found that a wagon load of broken stone measures 10% less in volume after it has traveled a short distance, due to the shaking down. In buying broken stone by the cubic yard it is well to bear this fact in mind.

Percentages of voids in sand are given in the section on Concrete. Consult the index under "Sand, Voids."

Sizes and Weight of Crushed Trap.—Mr. William E. McClintock gives the following data relative to Massachusetts trap rock: The rock weighs 180.7 lbs. per cu. ft. solid, or 4,879 lbs. per cu. yd. solid, being very heavy. The crushed trap of the Mass. Broken Stone Co., at Salem, weighs 2,586 lbs. per cu. yd., and has 47%

voids. A rotary screen is used 10 ft. long, 40 ins. diameter, with three sections 3½ ft., 3 ft. and 3 ft. long respectively, having circular holes ½-in., 1½ ins. and 3 ins. diameter. A bin holding 29 cu. yds. was used to measure the ½-in. screenings which were afterward weighed and found to average 2,605 lbs. per cu. yd. A box holding 1 cu. yd. was packed full with wet screenings which weighed only 2,480 lbs. The same box packed full of the same kind of screenings dry was found to hold 2,690 lbs. A bin holding 90 cu. yds. of the 1½-in. stone averaged 2,423 lbs. per cu. yd.; and a bin of the same size full of 3-in. stone, averaged 2,522 lbs. per cu. yd. This 3-in. stone was again measured in cars, and found to average 2,531 lbs. per cu. yd.

To determine the percentages of the different sizes, 19 cu. yds. of broken stone were measured and found to run as follows:

	Per cent.
½-in. trap	13.24
1½-in. trap	23.89
3-in. trap	62.87
Total	100.00

The tailings over 3 ins. in size were re-crushed.

Weight and Voids of Crushed Limestone.*—In 1906 the State Highway Commission of Illinois had a series of tests made at the state stone crushing plants at Menard and Joliet to determine what should be called a cubic yard of crushed stone. The results of these tests are given by Mr. A. N. Johnson, State Engineer. In making the tests both cars and wagons were loaded in different ways and hauled different distances. The contents of each car or wagon were carefully measured and weighed, and on arrival at destination again measured, so that the variation in the density of the load due to method of loading, to size of material and to settlement, was determined. From the results of these tests it will be seen that the average weight of the wagon loads of limestone, including all sizes, was, at the start, very nearly 2,400 lbs. per cubic yard, varying somewhat according to the method of loading, and that the weignt of a cubic yard in a wagon after it had been hauled a distance of one-half mile was a little over 2,600 lbs. Also, that the weight of a cubic yard of stone, as loaded in the cars, is but a few pounds over 2,400 and after settlement 2,600 lbs. As the weight of a cubic yard depends very considerably on the method of loading the car or wagon, and also as to the amount of settlement due to the length and character of the haul, the determination of what shall be the weight of a cubic yard is somewhat arbitrary. In view of the results of these tests, the State Highway Commission has adopted 2,500 lbs. as the weight of a cubic yard of crushed limestone at both the Menard and Joliet crushers.

*_Engineering-Contracting_, Apr. 3 and 10, 1907.

In the following tabulation is shown the weight per cubic yard of crushed limestone in carload lots and per cent of settlement in transportation, the haul in each instance being about 150 miles:

Size in inches.	Method of loading.	Weight in pounds per cubic yard when shipped.	Per cent of settlement.
Screenings,	15 ft. drop	2,500	9.5
"	"	2,509	12.5
"	"	2,530	9.8
3	Wheelbarrows	2,476	3.4
"	"	2,320	8.2
"	15 ft. drop	2,528	9.5
Screenings,	8 ft. drop	2,520	0.0
"	"	2,520	...
"	"	2,730	8.3
"	"	2,610	12.5
"	"	2,680	8.3
1½	"	2,570	1.4
"	"	2,210	13.9
"	"	2,360	8.7
"	"	2,300	13.6
"	"	2,180	7.4
"	"	2,200	9.7
"	"	2,250	7.7
3	"	2,520	3.8
"	"	2,440	3.4
"	"	2,500	5.0
"	"	2,380	12.9
"	"	2,300	3.7
"	"	2,400	0.0
"	"	2,290	9.0
"	"	2,270	7.4
"	"	2,275	9.2
"	"	2,240	11.1
"	"	2,260	10.5
"	"	2,470	....

To determine the effect of manner of loading, other experiments were made. In some experiments a box measuring 2.8 cu. ft. was used. No difference in the results, however, due to the size of the box could be detected. In every instance the voids were determined by weighing the amount of water added to fill the box. The tabulation is as follows:

Size.	Method of Loading.	Per cent of Voids.
3 in.	20-ft. drop	41.8
3 in.	15-ft drop	46.8
3 in.	15-ft. drop	47.2
3 in.	shovels	48.7
1½ in.	20-ft. drop	42.5
1½ in.	15-ft. drop	46.8
1½ in.	15-ft. drop	46.8
1½ in.	shovels	50.5
¾ in.	20-ft. drop	39.4
¾ in.	15-ft. drop	42.7
¾ in.	15-ft. drop	41.5
¾ in.	15-ft. drop	41.8
¾ in.	shovels	45.2
¾ in.	shovels	44.6
⅝ in.	shovels	41.0
⅝ in.	shovels	40.6
⅝ in.	shovels	41.0

Settlement of Crushed Stone in Wagons.*—The tests, the results of which are shown below, were made by the Illinois Highway Commission to determine the settlement of crushed stone in wagon loads for different hauls. The road over which the tests were made is a macadam road, not particularly smooth, but might be considered as an average road surface. The wagon used was one with a dump bottom supported by chains, which were drawn as tight as possible, so as to reduce the sag to a minimum. It will be noticed that about 50 per cent of the settlement occurs within the first 100 ft., and 75 per cent of the settlement in the first 200 ft. Almost all of the settlement occurs during the first half mile, as the tests showed practically no additional settlement for distances beyond.

Some of the wagons were loaded from the ground with shovels, others were loaded from bins, the stone having a 15-ft. drop, which compacted the stone a little more than where loaded with shovels so that there was somewhat less settlement. But at the end of a half mile the density was practically the same, whatever the method of loading. The density at the beginning and at the end of the haul can be compared by the weight of a given volume of crushed stone. For convenience, the weight of a cubic yard of the material at the beginning of the haul and at the end was computed from the known contents of a wagon.

Table V shows the per cent of settlement of crushed limestone in wagon loads at the end of different lengths of hauls:

Weight of Crushed Stone in Wagons and Cars.—In *Engineering-Contracting*, Aug. 5, 1908, are given in detail the results of some very careful tests made by Prof. Ira O. Baker on the voids in broken limestone of various sizes and after various drops and lengths of haul in wagons and cars. The following is a very brief summary of the results.

The following were the weights of broken stone per cubic yard in wagons and in cars, both at the crusher and after hauling a given distance:

		Wagon Loads.		Car Loads.	
Location of quarry.	Size of stone.	Wt. at crusher.	After a haul of ½ mile or more.	Wt. at crusher.	After a haul of 75 miles or more.
Joliet	½ in. Scr.	2303	2533	2659	2905
Joliet	¾ in Scr.			2652	2882
Joliet	2 in.-½ in.	2315	2480	2386	2592
Joliet	2 in.-¾ in.			2296	2516
Joliet	3 in.-2 in.			2361	2553
Chester	¾ in. Scr.	2442	2797	2546	2850
Chester	2 in.-¾ in.	2344	2582		
Chester	3 in.-2 in.	2367	2569	2348	2545
Kankakee	⅝ in. Scr.	2430	2697		
Kankakee	1¼ in.-⅝ in.	2325	2546		
Kankakee	2¼ in.-⅝ in.			2260	2390

The limestone came from Chester, Joliet and Kankakee, Ill., the specific gravity being 2.57, 2.71 and 2.61 respectively. There was

*Engineering-Contracting, April 24, 1907.

TABLE V.

Size.	Method of loading.	Length of Haul in Feet. 100	200	300	400	500	600	700	½ mile.	1 mile.	Weight per Cubic yard in pounds. At start.	At finish.
Screenings	15 ft. drop	...	...	...	...	...	...	...	11.5	11.5	2,518	2,840
Screenings	15 ft. drop	...	...	...	...	...	...	...	12.6	12.6	2.518	2,886
Screenings	15 ft. drop	7.3	8.3	8.9	9.2	9.5	10.1	10.1	11.2	....	2,450	2,780
Screenings	15 ft. drop	5.0	9.6	10.2	10.2	10.4	10.4	10.4	12.4	....	2,425	2,780
1½ inch	15 ft. drop	...	...	...	...	...	...	...	11.5	11.5*	2,305	2,600
1½ inch	15 ft. drop	5.3	6.2	7.1	7.7	7.9	8.0	8.3	9.2	....	2.380	2,625
1½ inch	15 ft. drop	2.6	3.7	4.9	5.3	5.3	5.3	5.4	5.4	....	2,450	2,600
1½ inch	Shovels	3.5	4.1	4.8	5.3	5.3	5.7	6.5	7.25	....	2,270	2,445
1½ inch	Shovels	...	...	...	...	...	...	...	12.6	12.6	2,305	2,642
3 inch	15 ft. drop	...	...	...	...	...	...	...	10.1	10.1	2,376	2,638
3 inch	15 ft. drop	3.5	4.2	4.5	4.8	5.0	5.0	5.0	6.0	....	2,360	2,505
3 inch	15 ft. drop	0.5	2.6	2.8	4.1	4.3	4.3	4.3	4.9	....	2,470	2,595
3 inch	Shovels	...	...	...	...	...	...	...	12.6	12.6	2,270	2,601
3 inch	Shovels	5.0	5.6	6.5	6.5	6.8	6.8	6.8	7.1	....	2,335	2,510

*Same per cent of settlement for two-mile haul.

no very marked variation in the voids for different sizes of stone, the range being from 43% for the 1¼ to 2¼-in. size of stone to 47% for screenings ⅝ in. and less.

When broken stone was shoveled or dropped into a wagon, and hauled, it settled about 4% during the first 100 ft. of haul, and about 4% more during the next half mile, a total of 8%, beyond which there was no settlement. Screenings settled more, about 6% in the first 100 ft., and a total of 12% at the end of a half-mile haul. A 75-mile haul in railway cars caused no more settlement than a half-mile haul in wagons.

The Per Cent of Voids in Railway Embankment.*—One of the editors of this paper, some years ago, built a section of a railroad in the South where many of the embankments were made from borrow pits, the material being solid rock. These pits were not cross-sectioned, and the specifications stated that when excavation was measured in embankment, that it should be considered that one yard of solid rock in place would make 1.75 cu. yds. in embankment. The editor protested against this, believing he was being deprived of from 15 to 20% of his yardage, but as he could show no authentic records to disprove the engineer's claim, he was paid on the basis given in specification.

We are able to give an example when it was possible to obtain the exact yardage taken from the cut, and the amount it made in the fill. At Boulder, Colo., in 1882, a cut of 3,600 cu. yds. made an embankment of 5,340 cu. yds., which is a ratio of 1 to 1.51.

In blasting rock for excavation on railroads, the mass comes out in pieces of all sizes, and as they are placed in the embankment voids of considerable size are made between the pieces. If the excavated rock has a layer of overlying earth that has not been stripped off before the rock is blasted, much of this earth, and the rock that is ground up fine, go to fill up these voids, making the embankment more compact than where there is no dirt excavated in connection with the rock. The result is that rock by itself "swells" more than it does when excavated in connection with earth and loose rock.

The writer's experience is that with solid rock first stripped and then excavated, the example given at Boulder is a fair average; but, with rock excavated where the solid rock is excavated in connection with loose rock and earth, this ratio of expansion is too high. For the last named excavation 1 to 1.4 is about the proper ratio.

Voids in Rock Blasted Under Water.†—Mr. E. C. Bowen is author of the following:

In Dredge Section 2 of the Ashtabula Dock Extension, Lake Shore & Michigan Southern Ry., which has just been finished by the Lake Erie Dredging Co. of Buffalo, the rock dredged was paid for by place measurement, there being 62,869 cu. yds. of rock so

---

**Engineering-Contracting*, Sept. 25, 1907.

†*Engineering-Contracting*, Nov. 6, 1907.

measured in this section. This was determined by careful soundings taken 6 ft. apart on ranges which were parallel lines spaced 6 ft. apart, both before and after dredging. The material dredged was shale rock which had been drilled and blasted, and which, after being dumped into scows, averaged about 25 lbs. per piece, in size.

Payments were made monthly and it was found impracticable to make place measurements each month on account of the large amount of floating plant engaged on the dock extension, which was in the way, and the often rough condition of Lake Erie. It was, therefore, decided to measure the material in scows and take a certain per cent of this as place measure until the final estimate when the total amount of material in this section would be determined by soundings taken before and after dredging. The sum of all partial payments previously made would then be subtracted from the above total, giving the amount of the final estimate.

The total amount dredged as measured in scows was 103,537 cu. yds. The amount of voids in the rock was, therefore, 39.3 per cent. Excavation was paid for 6 ins. below the required grade and no excavation was found by the soundings to have been carried below this level, which was 21.5 ft. below lake level.

A large amount of this material was used below water for filling the cribs forming the substructure of the docks and it was found to pack down very solidly. When exposed to air, however, it disintegrates rapidly.

Measurement of Rock.—Rock excavation is commonly measured in place before loosening, and paid for by the cubic yard of actual excavation; but, in sewer work and in tunnel work, if the contractor excavates beyond certain "neat lines" shown in the blue-prints, no payment is made, unless the specifications explicitly provide for payment for excavation beyond these "neat lines." In trench work, for example, a contractor often has to excavate from 6 to 18 ins. below the grade shown in the blue-print, because it costs less to do so than to work too close to the grade and afterward break off projecting knobs with a bull-point or otherwise. The same is true of shallow excavation, or skimming work, in road construction and the like.

The amount of rock taken out beyond the "neat lines" is called the "overbreak." For percentages of "overbreak" in tunnel work consult the index under Tunnels.

In examining specifications care should also be taken to note whether mention is made of rock slips or falls; for it often happens that after blasting to the neat lines a huge slide of rock occurs, possibly filling the entire excavation. Who is to stand the cost of removing this slide? If it is prescribed that the contractor shall, then he should study the dip of the rock and its character with this question of sliding in mind.

A perch of masonry is commonly taken as being 25 cu. ft. (or nearly 1 cu. yd.), but the original perch was a wall 12 ins. high, 18 ins. wide, and a rod (16½ ft.) long, making 24¾ cu. ft. In certain localities the "perch" is taken as being only 22 cu. ft., but in

most places in this country a perch is only 16½ cu. ft. These facts the contractor should know, for he must often deal with quarrymen who will not sell rock by the cubic yard.

In some localities stone for building is sold by the cord. Sedimentary rock quarried in slabs that are corded up carefully by hand may have 30% or less voids, which makes it evident that a contractor in buying rock by the cord should be careful to prescribe that it be packed closely and not dumped in piles helter skelter before measurement. In buying rock by the "cord" there is another precaution to be taken, and that is to specify how many cubic feet constitute a cord. A cord of wood is $4 \times 4 \times 8 = 128$ cu. ft., but a "cord" of stone is often $1 \times 4 \times 8 = 32$ cu. ft. Rock is often purchased by the ton of 2,000 lbs.; but to avoid lawsuits it is wise to define the word "ton" in any written or verbal contract, for a ton means 2,240 lbs. in some localities.

If crushed stone for macadam or ballast is purchased by the cubic yard measured loose, the precaution of stating where the measurement is to be made should always be taken. I have made measurements of wagon loads of broken stone after loading from chutes at the bins, and again after traveling for half a mile or more. A surprising shaking down, or settlement, always takes place, ordinarily making a reduction in volume of 10%. I announced these results in 1901, and recent experimenters have confirmed this percentage very closely.

There is another caution to be taken in examining specifications and in buying stone for concrete. Note whether or not the specification requires that the largest permissible stone shall pass *in every direction* through a ring of, say, 2½ ins. diameter. I have italicized the words "in every direction" because few engineers realize and few contractors stop to think that this virtually means the use of a much smaller opening in the screen than the one specified, in this case smaller than 2½ ins. In screening stone in a rotary screen, long narrow fragments will drop through a 2½-in. hole, yet many of these fragments will not pass "in every direction" through a 2½-in. hole. On this account, small though the matter seems, I once had more than 1,000 cu. yds. of stone rejected by an inspector who found that he could not pass through a ring some of the long fragments when laid crosswise.

There are two ways of designating the sizes of stone after screening. One is to designate the stone according to the diameter of the screen hole through which it has passed; in this case stone that has passed a 2½-in. hole is called "two and a half inch stone." Another, and very common way, is to take the diameter of the screen hole through which the stone did not pass, add it to the diameter of the screen hole through which the stone did pass, divide this sum by two, and call this average diameter the size of the stone. Suppose, for example, that a stone crusher were provided with a rotary screen having three sections of perforated metal, the holes in the first section being ¾-in. diameter, the holes in the second section 1½-in. and in the third section 2½-in. Then the

average size of the stone that passes the ¾-in. holes is ⅜-in. stone (assuming it to run from dust to ¾-in.). The average size of the stone that passes the 1½-in. holes but does not pass the ¾-in. holes, is (1½ + ¾) ÷ 2, or 1⅛-in., and it may be called 1⅛-in. stone. In like manner the stone between 1½-in. and 2½-in. may be called 2-in. stone. This rule is not followed strictly by the manufacturers of crushed stone, so it is always necessary to inquire exactly what they mean when they speak of stone of a certain size. Thus the Rockland Lake Trap Co. have the following schedule of commercial sizes:

Diameter of holes in screen, inches..	4¼	3¼	2¼	1 1/16	⅝
Commercial sizes of stone, inches....	3½	2½	1½	¾	½

Therefore, when "2½-in. stone" is ordered from this company, they ship a product that ranges from 2¼ ins. to 3¼ ins. in size—indeed, some of the stone fragments are even larger than 3¼ ins. in certain directions, for, as above stated, a long, narrow stone may pass through a screen.

Kinds of Hand Drills.—Drilling holes in rock by hand may be effected in three ways: (1) By a rotary drill or auger; (2) by a churn-drill; (3) by a hammer-drill, or "jumper" drill, struck with a hammer. A rock auger operated by hand is used only in very soft rock or coal.

A churn-drill, as its name implies, is raised and allowed to drop, or is hurled against the rock. For shallow holes of small diameter it is necessary to give a churn-drill additional weight, which is done by welding a ball of wrought iron to the center of the drill shank, making a ball-drill. A ball-drill is usually provided with a cutting bit at each end, and is operated by one man. For deep drilling, that is, for holes more than about 2½ or 3 ft. deep, an ordinary churn-drill is used, operated by one man for shallow work, two men for deeper work, and three or even four men for very deep holes where the weight of metal becomes considerable.

The churn-drill in the hands of a skilled driller is the most effective type of hand drill for vertical holes; and a little theory is not without its practical value in seeking the reason for the effectiveness of the churn-drill. Much of the energy of the blow of a hammer is lost in the form of heat at the head of the drill. This loss does not occur with the churn-drill. It takes some skill to start a hole with a ball-drill and to keep it plumb; but the time spent in acquiring this skill is repaid many times over if quarry operations with hand drills are to be moderately extensive.

The effect of the size of the hole upon the speed of drilling appears never to have been carefully determined. One authority says that to double the diameter of the hole decreases the speed of drilling by one-half. Another authority thinks that doubling the diameter divides the speed by four. According to the first authority, if a man could drill 12 ft. of 1-in. hole in a shift, he could drill only 6 ft. of 2-in. hole in a shift. According to the second authority, only 3 ft. of 2-in. hole could be drilled per shift.

Cost of Hammer Drilling.—The diameter of the hole, the angle at which the hole is driven and the presence or absence of water in the hole, all affect the cost of drilling by hand. The method of drilling with hammer-drills or with churn-drills is also an important factor in the cost. Obviously the character of the rock is the most important factor; but unfortunately very few reliable records of cost of drilling in different kinds of rock are to be found. From some observations on hammer drilling with a 1⅛-in. starting bit I have found that where one man is holding the drill vertically and two men are striking, the rate of drilling a 6-ft. hole is as follows:

	Ft. in 10 hrs.	Cost per ft., cts.
Granite	7	75
Trap (basalt)	11	48
Limestone	16	33

The cost is based upon a wage rate of $1.75 per 9-hr. day per man; and does not include the cost of sharpening drills, which may be taken at 5 to 8 cts. per ft. more.

I have found that a man drilling plug and feather holes in granite, each hole being ⅝-in. diam. by 2½ ins. deep, will average one hole in 5 mins., including the time of cleaning out holes, the driller striking about 200 blows in drilling the hole. No water is used in drilling these shallow holes, for the dust is readily and quickly cleaned out with a little wooden spoon. In 8 hrs. of steady work about 100 holes can be drilled, which is about 21 ft. of ⅝-in. hole. But in plug and feather work part of the time is spent in selecting rock, driving the plugs, etc., so that 50 or 60 holes drilled and plugged and feathered are generally counted a fair day's work.

I am indebted to Mr. John B. Hobson for the following data of hammer drilling in a British Columbia mine: Rock was augite diorite and firm red porphyry; starting bit, 1¾ ins.; finishing bit, 1¼ ins.; ⅞-in. steel; holes, 6 ft. deep; 8-lb. hammer. Two miners (one holding drill and one striking) averaged 14.8 ft. per 10-hr. shift. With wages at $2 a day the cost was nearly 28 cts. per ft. of hole.

Mr. Frank Nicholson states that in mining chalcopyrite in magnesian limestone at St. Genevieve, Mo., a day's work for a striker and a holder was 12 ft. of hole drilled. The drills had 1¼-in. starting bits, ⅞-in. octagon steel being used.

In excavating hard porphyry for the rock-fill dam at Otay, Cal., Mr. W. S. Russell states that a good day's work for three men drilling (one holding and two striking) was 6 to 8 ft. of hole, costing about 80 cts. per ft. of hole drilled. The holes were drilled 20 ft. deep vertically and sprung. This was an unusual depth of hole for hammer drilling, and accounts for the high cost per foot. It shows also how uneconomic is hammer drilling in deep vertical holes compared with churn drilling.

In driving a small (3 x 4½-ft.) tunnel through tough sandstone one driller averaged 4 to 5 holes, each 1½ ft. deep, per 8-hr. shift, using ⅞-in. bit for the starter; and, upon cleaning up, the advance

was 1 ft. per shift for one man. Each hole was charged with half a stick of 75% dynamite.

Cost of Hand Drilling in Granite.*—Mr. George C. McFarlane is authority for the following data on work done by him for Grand Trunk Pacific R. R., in Canada:

Steam drills were used in all the large cuts, while in the smaller cuts hand drills were used. With hand drills, holes as deep as 30 ft. were put down. Steel 1 in. in diameter was used to make the drills, which were gaged to 1⅝ in. This size drill was used for the entire depth of the hole. The hand drillers worked 3 men in a gang. In starting the hole, and until it reached a depth of about 6 ft., 2 men did the striking and one man held the drill. In drilling holes to a greater depth all three men used striking hammer, the rebound and jumping of the drill turning it enough to keep the hole fairly round. The rocks encountered on this work are hard granite, traps and diabase of the Laurentian and Huronian system.

Hand drillers, when working by the day, were paid $2.25 for 10 hrs., but, when paid per foot drilled, received 45 cts. This price per foot does not include sharpening or carrying steel to the shop. In drilling block holes, every hole less than 1 ft. in depth was counted as being a foot.

The following are some records of hand drilling:

One gang of three men, in drilling 10 to 14-ft. holes in dark hornblende, averaged 29 ft. per day.

In drilling red granite, 20 ft. is about the average per day.

In trap and diabase rock, 18 to 19 ft. is an average day's work.

In drilling block holes, a less number of feet is drilled per day. A record for six days for one gang on block-hole work was: Monday, 1 hole 36 ins. deep; 1 hole 45 ins. deep; 8 holes from 5 to 12 ins. deep; total driven, 11 ft. 7 in. Tuesday, 1 hole 22 ins.; 1 hole 18 ins.; 4 holes 6 to 9 ins.; total, 5 ft. 11 ins. Wednesday, 1 hole 36 ins.; 1 hole 22 ins.; 1 hole 17 ins.; 5 holes 6 to 12 ins.; total, 9 ft. 9 ins. On Thursday the drilling done was for holes to square up bottom of cut, there being 5 in all; 1 hole was 68 ins.; 1 hole 50 ins.; 1 hole 24 ins.; 1 hole 40 ins.; 1 hole 28 ins.; total, 17 ft. 6 ins. On Friday 11 holes from 6 to 16 ins. were driven. Saturday, 1 hole 44 ins.; 1 hole 30 ins.; and 7 holes from 6 to 9 ins.; total, 10 ft. 3 ins. This gives a total of 62 ft. 8 ins. in 49 holes, or an average depth of about 15 ins.

For sharpening the steel a blacksmith and a helper were employed, and a "nipper" to carry the steel back and forth from the cut and shop. For sharpening the steel for 5 gangs of drillers, who put down 2,142 ft. in a month, we have the following cost:

Blacksmith, 25 days at $3.50	$ 87.50
Helper, 24 days at $2.00	48.00
Nipper, 24 days at $2.00	48.00
12 sacks coal	12.00
	$195.50

*Engineering-Contracting, Nov. 27, 1907.

This means an average cost of sharpening per lin. ft. of hole drilled of about 9 cts.

This gives us a total cost of drilling and sharpening drills for the examples given as follows:

Dark hornblende (deep holes) 29 ft. drilled per day—	
Drilling, per ft.	$0.23
Sharpening, per ft.	0.09
Total, per ft.	$0.32
Red granite (deep holes), 20 ft. drilled per day—	
Drilling, per ft.	$0.34
Sharpening, per ft.	0.09
Total, per ft.	$0.42
Red granite (shallow block holes), 10 ft. 3 in. drilled per day—	
Drilling, per ft.	$0.65
Sharpening, per ft.	0.09
Total, per ft.	$0.74
Trap and diasbase (deep holes), 18 to 19 ft. drilled per day—	
Drilling, per ft.	$0.35
Sharpening, per ft.	0.09
Total, per ft.	$0.44
Average of 5 gangs, 18 ft. drilled each day—	
Drilling, per ft.	$0.37
Sharpening, per ft.	0.09
Total	$0.46

This gives an average of 19 ft. at a cost of 47 cts. per lin. ft. for drilling and sharpening steel. This includes both deep and shallow holes.

Cost of Churn Drilling.—I am indebted to Mr. W. M. Douglass, of the firm of Douglass Bros., contractors, for the following data on drilling with churn-drills, for railroad work in western Ohio. Three drillers were used for putting down the first 18 ft. of hole in blue sandstone the first day (10 hrs.), and four men were used for putting down the last 12 ft. of hole, so that it required 70 hrs. of labor at 15 cts. per hr., or $10.50, for a 30-ft. hole, making the cost 35 cts. per ft. In brown sandstone it required 70 to 80 hrs. labor to put down 30 ft. The drill holes were 2¾ ins. at top and 1½ ins. at bottom. Drilling with steam drills in this same stone, holes 20 ft. deep, cost 12 cts. per ft., including everything except interest, depreciation and drill sharpening. The cost of hand drilling agrees very closely with my own records of similar work in Pennsylvania.

Trautwine gives the following rates of drilling 3-ft. vertical holes, starting with a 1¾-in. bit, one man drilling with a churn-drill, shift 10 hrs. long:

Solid quartz	4 ft. in 10 hrs.
Tough hornblende	6 ft. in 10 hrs.
Granite or gneiss	7.5 ft. in 10 hrs.
Limestone	8.5 ft. in 10 hrs.
Sandstone	9.5 ft. in 10 hrs.

It should be observed that the holes in this case are shallow (3 ft.), and the diameter (1¾ ins.) is large for such shallow holes,

indicating that Trautwine's data applied to rock excavation where black powder was used.

Sizes of Air Drills.—The size of an air drill is denoted by the inner diameter of its air or steam cylinder; thus a 3¼-in. air drill is one having a cylinder 3¼ ins. diam.

The smallest sizes, 2¼-in. drill, is called a "baby drill," or a one-man drill—the latter name being given to the drill because it can readily be moved about and set up by one man. For narrow work in mines the baby drill is adapted. It is also used for drilling plug and feather holes, and might often be used profitably for shallow cuts and trenches. The most commonly used sizes for general contract work, tunneling and mining are the 3⅛-in. and the 3¼-in. drills. The drill is churned back and forth in the hole by compressed air or steam power, and after each stroke it is mechanically turned a fraction of a circle. The drill is fed forward by hand, a crank at the end of a feed-screw being used for this purpose. A longer drill is inserted every 2 ft. in depth of hole, for 2 ft. is the limit of feed of the ordinary feed-screw used.

Data as to Rock Drills.—Table VI gives approximately the principal data regarding air drills.

Test of Air Consumption at the Rose Deep Mine.—A 6-hour run at the Rose Deep Mine, South Africa, showed the following results for 31 drills: The compressed air averaged 70 lbs. per sq. in. and each 3¼-in. drill consumed 81 cu. ft. of free air per minute, including all leakage of pipes (there was less leakage than is common in mines). Each drill required 43 lbs. of coal per hour, to supply this compressed air; and each 3.4 lbs. of coal developed 1 hp. per hr., by the indicator on the steam engine, evaporating 6.74 lbs. of water from 212° F. The average horsepower of the compressor engine was 12.7 I. H. P. per drill; but all the drillers were trying to make a record, and accomplished in 6 hrs. an amount of drilling that ordinarily took 8 hrs. The power plant was a vertical King-Reidler Compound Steam and Double Stage Compressor, with two boilers of the horizontal return tubular type.

Tables of Air Consumption in Catalogues.—Table VII is given in the catalogue of one of the well-known drill manufacturers, and is said to be based upon actual tests of single drills running continuously without stops for changing bits, etc.

TABLE VII.—CUBIC FEET OF FREE AIR PER MINUTE REQUIRED TO RUN A ONE-DRILL PLANT.

	Diameter of Drill Cylinder												
Gauge pressure.	2 in.	2¼ in.	2½ in.	2¾ in.	3 in.	3⅛ in.	3 3/16 in.	3¼ in.	3½ in.	3⅝ in.	4¾ in.	5 in.	5½ in.
60	50	60	68	82	90	95	97	100	108	113	130	150	164
70	56	68	77	93	102	108	110	113	124	129	147	170	181
80	63	76	86	104	114	120	123	127	131	143	164	190	207
90	70	84	95	115	126	133	136	141	152	159	182	210	230
100	77	92	104	126	138	146	149	154	166	174	199	240	252

When more than one drill is to be supplied from the same air

TABLE VI.

Diameter of cylinder, ins.	2¼	2½	2¾	3⅛	3¼	3⅝
Length of stroke, ins.	5	6	6½	6⅝	6⅝	7¼
Length of drill from end of crank to end of piston, ins.	36	43	50	50	50	52
Depth of hole drilled without change of bit, ins.	15	20	24	24	24	24
Diameter of supply inlet (standard pipe) ins.	¾	¾	¾	1	1	1¼
Approximate strokes per minute with 60 lbs. pressure at drill	500	450	375	350	325	300
Depth of vertical hole each machine will drill easily, ft.	6	8	10	14	16	20
Diameter of holes drilled as desired from, ins.	¾ to 1½	1 to 1½	1½ to 2¼	1½ to 2¼	1¾ to 2¾	1¾ to 3
Diameter of octagon steel used, ins.	¾ to ⅞	⅞ to 1	1 to 1⅛	1⅛ to 1¼	1⅛ to 1¼	1¼-1⅜
Best size of boiler to give plenty of steam at high pressure	6 H.P.	8 H.P.	8 H.P.	9 H.P.	10 H.P.	12 H.P.
Best size of supply pipe to carry steam 100 to 200 feet, ins.	¾	¾	¾	1	1	1¼
Drill unmounted with wrenches and fittings, not boxed, lbs.	128	190	265	315	285	390
Tripod without weights, not boxed, lbs.	80	160	160	160	210	275
Holding down weights, not boxed, lbs.	120	270	270	285	330	375
Drill, tripod, weights and wrenches boxed, lbs.	415	660	820	885	952	1230
Drill unmounted with wrenches and fittings without tripod or column	$170	$200	$225	$250	$275	$295
Tripod and weights	$30	$50	$50	$50	$50	$55

compressor the manufacturers advise multiplying the quantities given in Table VII by the factors given in Table VIII.

TABLE VIII.

Number of drills....	1	2	5	10	15	20	30	40	70
Multiply value in Table VII by......	1	1.8	4.1	7.1	9.5	11.7	15.8	21.4	33.2

Tables similar to these are given by other manufacturers. In answer to letters of inquiry I have been informed that such tables are "based upon experience in a large number of mines."

The actual drilling time, that is, the time when the drill is actually striking blows, is seldom over 70%, and often not more than 40% of the length of the shift. Knowing the conditions of work, the reader will be able (with the aid of data given subsequently) to predict approximately the per cent. of actual drilling time. Then, if there are more than, say, 10 drills, he can multiply the air consumption of one drill (when actually drilling) by the percentage of drilling time in the shift, and the product will be the average air consumption of each drill. If there are less than about 10 drills it will not be safe to figure so closely, because the fewer the drills operated from one compressor, the more likely is it that all or nearly all of them will be using air at the same time. The larger the number of drills, on the other hand, the more certain it is that some will be changing bits while others are drilling, and thus draw a steady, average amount of air from the compressor.

Steam Consumption.—When steam is piped directly from the boiler into a drill, practically the same number of cubic feet of steam are consumed as of cubic feet of compressed air. We may assume that a cubic foot of steam will do practically the same work in a drill as a cubic foot of compressed air at the same pressure, because neither the steam nor the air acts to any great extent expansively in a drill cylinder, due to the late cut off. This being so, 0.21 lb. of steam is equivalent to 6 cu. ft. of free air, or 1 lb. of steam is equivalent to nearly 30 cu. ft. of free air, or 1 cu. ft. of free air is equivalent to 0.035 lbs. steam—all at the same pressure of 75 lbs. per sq. in. If a drill consumes at the rate of 100 cu. ft. of free air per min., it will consume 6,000 cu. ft. of free air in an hour. If it were using steam in its cylinder instead of air (at 75 lbs. pressure), it would, therefore, consume $6,000 \times 0.035 = 240$ lbs. of steam (at 75 lbs. pressure) in an hour.

When coal is burned under a boiler a large percentage of its heat passes up the chimney in the gases and is lost; and in addition to this loss the boiler itself radiates heat constantly. The greater part of the loss occurs in the heat that goes up the chimney. In large, well-designed boilers, properly protected by asbestos or similar covering, the coal burned will develop steam to about 80% of the full heat value of the fuel; the efficiency of the boiler and furnace is then 80%. In locomotive boilers, where forced draft is used, firing not of the best and boiler exposed to moving air, the efficiency

is often as low as 45%. The efficiency of a good boiler of moderate size (100 hp.), well housed, is ordinarily about 75%. A small (20 hp.) boiler exposed to the wind has an efficiency of about 60% when not forced. If a small boiler is used to run one drill, the boiler must always have up enough steam to keep the drill running at nearly full capacity; but when the drill is stopped, during the changing of bits, moving, etc., there is a waste of steam, because the period of stoppage is not long enough to permit the fireman to make any material change in the firing and in the draft.

When a ¾-in. drill is operated by steam from a small boiler, about 600 lbs. of coal are ordinarily required per 10-hr. shift. But if a number of drills are supplied from a large, well lagged boiler, through steam pipes that are also lagged with asbestos covering, it is possible to cut down the coal consumption to 300 lbs. or less per drill per 10 hrs.

Gasoline Air Compressors.—Where not more than three or four drills are to be operated, probably no power can equal compressed air generated by gasoline. One pint of gasoline per hour per brake horsepower (B. HP.) of gasoline engine may be counted upon as the average consumption. It will require about 12 hp. to compress air for each drill (3¼-in. size); hence 12 pints, or 1½ gals., of gasoline will be required per hour per drill while actually drilling. Since gasoline air compressors are self-regulating, when the drill is not using air very little gasoline is burned by the gasoline engine driving the compressor. If the drill is actually drilling two-thirds of the working shift, we may safely count upon using about 1 gal. of gasoline per hour of shift per drill, or 8 gals. per shift of 8 hrs. long. If gasoline is worth 15 cts. per gal., delivered at the engine, one drill consumes only $1.20 worth of gasoline per shift of 8 hrs. A gasoline compressor possesses other very important economic advantages over a small steam-driven plant. First, there is the saving in wages of firemen; for, once started, a gasoline engine runs itself. Second, there is the saving in hauling or pumping of water and the hauling of fuel. Third, the cost of gasoline is often less than the cost of coal for operating a small plant.

Percentage of Lost Time in Drilling.—In operating machines of any kind the percentage of lost time is a factor that should receive the most careful consideration. The most serious loss of time in machine drilling is the time lost in changing bits and pumping out the hole; for, with a 2-ft. feed screw (which is the ordinary length), a new drill must be inserted for every 2 ft. of hole drilled. It takes from 4 to 16 minutes to drill 2 ft. of hole, counting the actual time that the drill is striking, and it ordinarily takes from 2 to 5 minutes to change bits and pump out the hole. I have often timed the work, however, where 9 minutes were spent in drilling, followed by 9 minutes lost by lazy drillers in changing bits. Counting no other time losses, then, half the available time was lost in the operation of changing bits. When shallow holes (6 ft. or less), are to be drilled, the drill steel is light, and there is often little

or no sludge pumping to be done. In such cases it is possible for the driller and his helper to change bits in 1 minute, or even less when they are rushing the work. So far as the changing of bits is concerned, men should be made to work with a vim. When men have to exercise their muscles incessantly for 8 or 10 hrs. there is reason in taking a slow, steady gait, but in machine work, muscular exercise is intermittent, and should be vigorous.

Next in importance to the time lost in changing bits is the time lost in shifting the machine from hole to hole. To move a tripod from one hole to the next and set up again ready to drill seldom consumes less than 7 minutes, even when the two men are working rapidly, when the distance to move is short, and when the rock floor is level and soft. When, however, the rock floor is irregular and hard, requiring the vigorous use of gad and pick, not only in making holes for the tripod leg points to rest in, but requiring, also, some little time in squaring up a face for the bit to strike upon, the two men may consume from 30 to 45 minutes, shifting the machine and setting up, if they work deliberately. In such cases it is advisable to have laborers working ahead of the drillers preparing the face of the rock, leveling the site of the hole, removing loose rock, etc. One can see clearly what a great saving in time may thereby be effected; yet, this simple expedient is seldom adopted; but the driller and his helper are usually left to themselves in preparing the ground for each new set up. Excluding the time required to change bits for the new hole, we may say that two men can ordinarily make a new set up with a tripod in 12 to 15 minutes, if they work rapidly.

Rule for Estimating Feet Drilled Per Shift.—We are now possessed of sufficient data to enable us to formulate a rule whereby the number of feet drilled per shift, under given conditions, may be predicted. I will not go into the method that I used in deducing the following rule, which is strictly correct, for the method is one of simple arithmetic. The rule is:

To find the number of feet of hole drilled per shift divide the total number of working minutes in the shift by the sum of the following quantities: The number of minutes of actual drilling required to drill one foot of hole, plus the average number of minutes required to change bits divided by the length of the feed screw in feet, plus the average number of minutes required to shift the machine from hole to hole divided by the depth of the hole in feet.

Suppose, for example, the shift is 10 hrs. long, that is, 600 mins.; that it requires 5 mins. to drill 1 ft. of the rock; that it requires 4 mins. to change bits and clean hole; that the feed screw is 2 ft. long; that the machine can be shifted from hole to hole in 16 mins.; and that each hole is 8 ft. deep. Then according to the rule we have: The number of feet of hole per shift is $600 \div (5 + \frac{4}{2} + \frac{16}{8})$, which is equivalent to $600 \div 9$, or $66\frac{2}{3}$ ft. drilled per 10-hr. shift.

For those who can use simple algebraic formulas the above rule is much more compactly expressed in the following formula:

$$N = \frac{S}{r + \frac{m}{f} + \frac{s}{D}}$$

N = number of feet drilled per shift.

S = length of working time of shift in minutes = 600 for a 10-hr. shift when no time is lost by blasts, breakdowns, etc.

r = number of minutes of actual drilling required to drill 1 ft. of the rock.

m = number of minutes required to crank up, change drills, pump out hole and crank down.

m = 3 to 4 mins. ordinarily.

f = length of feed screw, in feet, ranging from 1¼ ft. in "baby" drills to 2½ ft. in largest drills, but ordinarily 2 ft.

s = number of minutes required to shift machine from one hole to the next, including the time of chipping and starting the new hole, but not including the time of cranking up and cranking down. s ranges from 5 mins. for very rapid shifting on level rock, to 40 mins. for very slow shifting on irregular rock.

D = depth of hole in feet.

Even a casual study of the foregoing formula, or rule, must impres the practical man with the importance of the lost time elements in machine drilling; consequently of the value of timing the operation of changing bits and moving machines when the men do not know that they are being timed. Another feature that stands out strikingly is the reduced output of a drill working in a shallow hole. Let the reader solve a few problems, assuming first an average depth of hole of 16 ft. and finally an average depth of only 2 ft. (such as occurs often in the skimming work in road building), and he will never make the blunder of the contractor who bid the same price for rock excavation on the 2-ft. deepening of the Erie Canal as had been bid for the 36-ft. excavation on the Chicago Canal.

If we assume that the shift is 10 hrs. long; that the rate of drilling is 1 ft. in 5 mins.; that it takes 4 mins. to change bits and pump out the hole at each change of bits; that the feed screw is 2 ft. long; and that it takes 15 mins. to shift from one hole to the next; by applying the rule we obtain the following results:

Depth of hole, ft.	1	2	3	5	10	15	20
Feet drilled in 10 hrs.....	27	41	50	60	70	75	80

When drillers are lazy they may readily consume 8 mins. in changing bits and pumping out the hole each time. With all conditions the same as before, excepting that 8 mins. are consumed in changing bits, we have the following results:

Depth of hole, ft.	1	2	3	5	10	15	20
Feet drilled in 10 hrs.....	25	36	43	50	57	60	62

It will be seen that in deep hole drilling 20% decreased efficiency results from just a little laziness in changing bits, under the condi-

tions assumed; and in softer rocks the percentage of decreased efficiency is much greater. Where the holes are shallow the time involved in shifting from one hole to the next becomes an important factor. Assuming that the conditions are the same as in the first instance, except that 30 mins. are consumed in shifting from one hole to the next, then we have the following results:

Depth of hole, ft.	1	2	3	5	10	15	20
Feet drilled in 10 hrs.	16	27	35	46	60	67	70

Rates of Drilling in Different Rocks.—Unfortunately no published record exists showing rates of drilling in different kinds of rock with given air or steam pressures and given sizes of drill bits. Such scattering records as are to be found merely give the feet of hole drilled per shift. From data obtained by observation I have compiled the following table for drilling with 3⅛-in. machines using air or steam at 70 lbs. pressure, starting bit about 2¾ ins. and finishing bit about 1½ ins.:

	Time to drill 1 ft.
Soft sandstones, limestones, etc.	3 mins.
Medium, ditto	4 mins.
Hard granites, hard sandstones, etc.	5 mins.
Very hard traps, granites, etc.	6 to 8 mins.
Very soft shales, and other rocks that make sludge rapidly and when a water jet is not used	8 to 10 mins.

That the inexperienced reader may have a good general conception of what constitutes a day's work under ordinary conditions the following summary may be of benefit: In drilling vertical holes, with the drill on a tripod, the holes being from 10 to 20 ft. deep, shift 10 hrs. long, I have found that in the hard "granite" of the Adirondack Mountains, New York, 48 ft. is a fair 10-hr. day's work. In the granites of Maine and Massachusetts 45 to 50 ft. is a day's work. In New York City, where the rock is mica schist, deep holes are drilled at the rate of 60 to 70 ft. per 10-hr. shift by men willing to work, but 40 to 50 is nearer the average of union drillers. In the very hard trap rock of the Hudson River 40 ft. is considered a fair day's work. In the soft red sandstone of northern New Jersey 90 ft. are readily drilled per day wherever the rock is not so seamy as to cause lost time by the sticking of the bit; in fact, I have records showing 110 ft. per 10-hr. shift in this rock. In the hard limestone near Rochester my records show about 70 ft. per 10-hr. shift. In the limestone on the Chicago Drainage Canal 70 to 80 ft. was a 10-hr. day's work. In the hard syenite of Douglass Island, in open pit work, and where it is difficult to make set-ups, 36 ft. was the average per 10-hr. day. In the granites encountered in grading for the Grand Trunk Pacific R. R. in Canada, only 30 ft. were averaged per drill per day. In the limestone near Windmill Point, Ontario, 3⅝-in. drills average 75 ft. a day (holes 18 ft. deep); 2¾-in. drills, 60 ft. a day, and "baby" drills, 37 ft. a day.

The foregoing examples all apply to comparatively deep vertical holes, in open excavation. In tunnel work there is no reason why a drill should not do about the same work per shift, were there no delays in timbering, mucking, waiting for gases to clear, etc. Such delays, however, often reduce the drill footage very much.

Cost of Sharpening Bits.—One blacksmith (with a helper) will sharpen about 140 bits a day, and under ordinary conditions will keep 5 to 7 drills supplied with sharp bits. On average rock a bit must be sharpened for every 2 ft. hole; in very soft rock a bit for every 4 ft., and in very hard rock a bit for every 1⅓ ft. of hole. On small jobs it is often necessary to have a blacksmith, even though there is only one drill at work. In such cases, however, the blacksmith should be kept busy with other work.

Cost of Drill Repairs.—Mr. Thomas Dennis, agent of the Adventure Consolidated Copper Co., Hancock, Mich., has kindly furnished the following data of the average monthly cost of keeping a drill in repair:

Supplies for repairs	$ 1.31
Machinist labor	8.45
Blacksmith labor	1.60
Total repair charge per month	$11.36

The number of drills in the shop at any one time is about 15% of the total number. This low cost is based upon work where a large number of drills are used and well handled by the users.

I am indebted to Mr. Josiah Bond, mining engineer, for the statement that the cost of repairs averages 50 cts. per drill per shift in mines where a few drills are operated and renewal parts purchased from the manufacturers. In open cut work my experience is that 75 cts. per drill per shift is a fair allowance for renewals and repairs. In the gold mines of South Africa, where each drill works two shifts per day, the cost of drill repairs is $300 per drill per year; while the first cost of a 3¼-in. drill with bar is $185, according to a recent report of the Government Mine Inspector.

Mr. Josiah Bond, General Manager American Copper Mining Co., Somerville, N. J., wrote me as follows:

"As to the matter of drill repairs, I can give you only a few figures. In using drills for years, I find I have accurate figures for drill repairs for only three years. These place the repairs per drill at $102.00, $100.50 and $93.76 per year. My opinion is that a drill used night and day for a year is sufficiently worn to make it good business to throw it away; though if a drill is used by only one man, and he is made responsible for its condition, I think the life of a drill is at least three years (one shift). Of course, studs and side rods will have to be replaced occasionally, and other small repairs must be made. A well-made heavy bar or column should outlast four drills, and arms are probably strong enough to kill three drills. And the drill itself is the weak part; as soon as the cylinder and piston are enough worn to make a day's work only 80 ft. instead of 120, or even 100 ft., it is clear that you are losing money by keeping it at work. I have always wanted two idle drills and one idle column and arm, etc., for five working drills. From my practice, which has been a pretty hard one, developing with low-priced labor, I should estimate a stoping drill to cost, including repairs and its own life, about 50 cts. per shift.

"Where an operation is large enough to warrant the erection of a

machine shop, sufficiently equipped to make all parts of drills, this cost can probably be cut in two; and in old mines, even without this, where the work is more regular, a saving can be made, because breakages do not occur so often. My practice has been without the luxury of a good shop, and all repairs are purchased, with the exception of a few of the simple parts, like side rods, etc.

"Much depends on the care given a drill, and the rock to be drilled makes a great difference also, but the above figures are, I should hope, outside prices; but in my work, drills have always been a secondary consideration."

The following table gives the cost of repairing 25 drills for 11 months in 1905, at the Wabana Iron Mines, Nova Scotia:*

Month of	Total repairs.	Amt. per drill per month.
January	$ 68.32	$2.86
February	85.53	3.576
March	165.10	6.007
April	33.92	1.21
May	46.98	1.86
June	49.41	1.98
July	110.89	4.49
August	316.81	13.50
September	140.62	5.20
October	259.60	10.66
November	204.75	7.80
Total and av.	$1,481.93	$5.40

In addition to this add $1.75 per day for labor or 7 cts. per drill per day, or $2 per month, making a total of $7.40 per drill per month.

The average cost of repairs was $5.40 per month per drill (drills worked one shift only each day), not including the cost of labor of repairing. It takes all of one man's time, at $1.75 per day, keeping the drills in repair, or practically $2.00 per month per drill. The parts used in making repairs are all bought of the manufacturers. We see that the total cost of drill repairs has been about $7.40 per drill per month, or 30 cts. per drill per 10-hr. day, which is a very moderate cost, and speaks well not only for the make of the drills, but for the care given to them.

Cost of Operating Drills.—When operating a single (3¼-in.) drill supplied by steam from a small portable boiler, I find the cost is usually as follows for a 10-hr. shift:

1 drill runner	$ 3.00
1 drill helper	1.75
1 fireman	2.00
660 lbs. of coal (0.3 ton at $3)	.90
Water, if hauled, say	.75
Hauling and sharpening 30 bits (incl. new steel) at 4 cts.	1.20
Repairs to drill and hose renewals	.75
Total per 10 hrs.	$10.35

The foregoing is merely an example, based, however, upon several different jobs; but in each case the accessibility of a blacksmith, the nearness to water, the price of coal delivered at the

*See *Engineering-Contracting*, February 1, 1906, p. 42.

boiler, etc., must be determined before an accurate estimate can be made. If 4 drills, for example, are to be operated from the same boiler, the fuel bill will be somewhat reduced even if the pipes are not covered with asbestos, and of course the wages of the fireman will be distributed over 4 drills. It will then pay to have a blacksmith at hand. If 10 or more drills are run by steam from a central boiler, and if the main pipes are lagged, the fuel should not much exceed 300 lbs. per drill per 10-hr. shift. By the rules previously given a fairly close estimate can be made of the number of feet of hole that each drill should average. If 60 ft., for example, are to be a fair day's work in limestone or sandstone, we have $10.35 ÷ 60 = 17 cts. per ft. as the cost, exclusive of superintendence, plant installation and plant rental.

If a central compressor or steam plant supplies power for, say, 15 drills, we may estimate the cost of operating each drill as follows:

1 drill runner	$3.00
1 drill helper	1.75
1-15 fireman at $2.25	.15
1-15 compressor man at $3	.20
300 lbs. coal (water nominal) at $3 ton	.45
Sharpening bits, 30 at 3 cts.	.90
Repairs to drill, hose, etc.	.75
Total for 60 ft. of hole at 12 cts.	$7.20

If the cost of each drill and 1/15 part of the compressor plant is $350, and 30% of this is assumed as a fair allowance for annual plant rental, we have $105 to charge up against each drill for "rental," or about 50 cts. per shift if 200 shifts are worked each year, or about 1 ct. per ft. of hole drilled.

In my book "Rock Excavation—Methods and Cost" will be found detailed data on the cost of drilling blast-holes with well-drillers of the "Cyclone" type. The holes were 3 ins. diam. × 24 ft. deep in sandstone and cost 12½ cts. per ft. to drill. Other data on drilling with well drillers will be found in this handbook, page 253.

Piece Rate and Bonus System in Drilling.—The original "hole contract system" was a piece rate system, whereby the driller was paid for his work according to the number of lineal feet of hole drilled. I have modified the original system by paying the drillers a daily wage plus a bonus for each lineal foot in excess of a stipulated minimum. See Section I of this book.

Cost of Loading by Hand.—Where a laborer has merely to pick up and cast one-man stone into a jaw crusher, I have had men average 34 cu. yds. of loose stone handled per man per 10-hr. shift, which is equivalent to about 20 cu. yds. of solid rock. This, I believe, marks the maximum that may be done, day in and day out, by a good worker, where the stone has scarcely to be lifted off the floor to toss it into the jaws. Every stone, however, was handled and not shoved or slid into the crusher.

On the Chicago Canal the average output per man per 10-hr. shift was about 7 cu. yds. loaded into dump cars, and this included some sledging. The average per man loading into the low skips used on the cableways, involving very little sledging, was about

10 cu. yds. of solid rock per man per 10-hr. shift. The best day's record was 16.6 cu. yds. per man loading into skips. In loading cars about 5 men out of the force of 36 loaders were kept busy sledging the rock; but with the cableways not only was it easier to roll large rocks into the skips (or "scale pans"), but very large rocks were lifted with grab hooks and chains and carried to the dump without sledging.

In loading wagons with stone readily lifted by one man, the wagon having high sides, I have found that a man will readily average 10 cu. yds. solid, which is equivalent to 17 cu. yds. loose measure per day of 10 hrs. The same man will throw the stone out of the wagon twice as fast as he will load it, and this does not mean dumping the wagon, but handling each stone separately. In loading a wagon having a stone-rack, and no sides, two men, passing stone up to the driver, who cords the stone on the rack, will load 1 cu. yd. solid stone in 13 mins. when working rapidly, but this is too high an average to be maintained steadily for a full day. A driver will unload 1 cu. yd. solid (or 1.7 cu. yd. loose) from such a stone-rack, by rolling the stone off, in 7 mins. if he hurries, but he may take 20 mins. if he loafs. A man will readily load a wheelbarrow with stone already sledged and ready for the crusher at the rate of 12 cu. yds. solid (or 21 cu. yds. loose) in 10 hrs.

Cost of Handling Crushed Stone.—In handling stone after it has been crushed to 2½-in. size, or smaller, a shovel is used, and the output of a man depends very largely upon whether he is shoveling stone that lies upon smooth boards or upon the ground. I have often had 6 good shovelers unload a canal boat holding 120 cu. yds. loose measure of crushed trap rock (2-in. size) in 9 hrs., but after breaking through to the floor the shoveling was comparatively easy; this is 20 cu. yds. loose (or 12 cu. yds. solid) per man per day shoveled into skips. In shoveling from flat cars into wagons the same rate can be attained, but in shoveling from a hopper-bottom car, where there is at no time a smooth floor along which to force the shovel, an output of 14 cu. yds. loose measure (or 8 cu. yds. solid) is a fair 10-hr. day's work. In shoveling broken stone off the ground into wagons it is not safe to count upon much more than 12 cu. yds. loose measure (or 7 cu. yds. solid) per man per 10 hrs. A careful manager will, if possible, provide a smooth platform, preferably faced with sheet iron, upon which to dump any stone that is to be re-handled by shovelers. Small stone, ¾ in. or less in diameter, is easily penetrated by a shovel and need not be dumped upon a platform. A clamshell bucket operated by a locomotive crane, or derrick, is doubtless the most economic method of loading broken stone from cars or stock piles, where the quantity to be handled warrants the installation.

Cost of Unloading Broken Stone With a Clamshell Bucket.*—A

Engineering-Contracting, Oct. 3, 1906.

novel expedient for increasing the power of a derrick was practiced recently in an extensive piece of concrete work involving the unloading of broken stone from vessels into wagons. The work in question was retaining wall work on track improvements on the New York Central & Hudson River R. R., at Ossining, N. Y. Scows brought broken stone to an adjacent wharf and the plan was to unload the stone into wagons, using a stiff leg derrick equipped with a clamshell bucket. The derrick at hand was an ordinary affair, with 10 x 10-in. mast, 8 x 8-in. stiff legs, and a 40-ft. boom, operated by a 5 x 10-in. National double drum hoisting engine, capable of handling a 3,000-lb. load with the ordinary single line rigging. As the clamshell weighed 2,500 lbs. empty and fully 4,700 lbs. when loaded with broken stone, some expedient was necessary to carry out the plan. The problem was finally worked out as follows:

The bucket was suspended from the boom by a chain of just sufficient length to allow it to open and close. The end of the hoisting line was also fastened to the end of the boom and run over a single block attached to the closing wheel on the bucket, then through the sheave of the boom and thence to the engine drum, making a double line which gave the engine sufficient power. The loss of speed resulting was of little moment. The stone was unloaded directly into wagons so that the hoisting distance was very small, and the time consumed in swinging was greater than the time necessary to hoist. The result was that there was practically no reduction of speed of operation. The hoisting was done, of course, by raising and lowering the boom, using the second drum of the engine.

The derrick was operated by an engineman and a helper and handled regularly 100 cu. yds. per day. In addition to the derrick work there were 24 hrs. labor on a 500 cu. yd. boat load cleaning out the stone that could not be reached by the bucket. The labor cost of unloading vessels into wagons, using the apparatus described, can then be itemized as follows:

One engineman, at $2.50	2.5 cts. per cu. yd.
One helper, at $1.50	1.5 cts. per cu. yd.
Labor, cleaning	0.7 ct. per cu. yd.
Total labor cost	4.7 cts. per cu. yd.

Cost of fuel would not add more than 1½ ct. per cu. yd., making a total of about 5¼ cts., to which should be added cost of erecting and removing the plant, and plant maintenance.

The total cost of the derrick fitted as described was $1,500. The work in connection with which the derrick was used is being done by Ford & Waldo, Engineers and Contractors, Park Row Building, New York, N. Y., and the double line rigging was devised by them.

Unloading Scows With a Clamshell.—In building the masonry anchorage for the Manhattan Bridge, Mr. Gustav Kaufman used a 1⅝ cu. yd. Hayward clamshell bucket operated by a 50-hp. electric motor, and unloaded 600 cu. yds of broken stone per day from scows. In addition to the operator of the clamshell bucket, about 8 men

were kept busy trimming up the stone in the scow not handled by the bucket. The clamshell bucket dumped into a 10 cu. yd. hopper provided with a shaking chute which fed the stone onto a Robins belt conveyor. Careful timing showed that the bucket made 1 1/9 scoops per minute, averaging 0.9 cu. yd. per scoop. Tests showed that it required 20 hp. while loading, 42 hp. while lifting, 42 hp. while swinging loaded, and 20 hp. while swinging back empty. But if we assume a constant average expenditure of 30 hp., we have about 24 kw., or 240 kw. hrs. per day. Based upon these data we would have the following approximate cost:

	Per day.	Per cu. yd. Cts.
1 operator	$ 3.00	$0.5
240 K. W. hrs. electricity at 4 cts.	9.60	1.6
8 laborers at $1.75	14.00	2.4
Total	$26.60	4.5

Another ½ ct. per cu. yd. would cover the plant interest and maintenance.

Cost of Handling Broken Stone With a Derrick.—Where crushed stone must be handled with a derrick, as in unloading boats, I have found the following to be about the best that can be done per day:

	Per day.
6 shovelers, at $1.50	$ 9.00
1 hooker on	1.50
2 tagmen (swinging the boom)	3.00
1 dumpman	1.50
1 water boy	1.00
1 team on derrick	3.50
1 foreman	3.00
120 cu. yds. (loose) at 19 cts. =	$22.50

It commonly costs about 25 cts. per cu. yd. (loose measure) to unload a boat of broken stone using skips holding 18 cu. ft. each, and a team on the derrick for raising them. Where any great amount of such work is to be done, however, a hoisting engine and a derrick provided with a bull-wheel should be used. The following shows the cost of unloading flat cars containing broken stone (2-in. size), using a derrick with a bull-wheel for "slewing" the boom:

5 shovelers, at $1.50	$ 7.50
1 dumpman	1.50
1 engineman	2.50
½ ton coal at $3	1.50
100 cu. yds. (loose) at 13 cts. =	$13.00

In this case a stiff-leg derrick, 40-ft. boom, with a bull-wheel, operated by a double cylinder (7 x 10) engine, handled self-righting steel buckets holding 20 cu. ft. each. Water for the engine was delivered in a pipe. The engineman was the foreman.

In neither of the two cases just cited is the cost of installing the derrick included, nor is the interest and depreciation of plant included. It takes 6 men and a foreman one day to dismantle and move a stiff-leg derrick a short distance (100 or 200 ft.), and one

more day to set it up again, or $26 for the two days' work. This includes moving the engine and the stones used to hold the stiff legs down; and it applies to a slow gang of workmen.

A guy derrick with a 50 or 60-ft. boom swung by a bull-wheel and a hoisting engine will often prove the cheapest device for loading cars with blasted rock. If the derrick is handling skips loaded with stone, the following is a fair average of the time elements in handling each skip load:

Changing from empty to loaded skip	35 secs.
Swinging (half circle)	20 secs.
Dumping skip	15 secs.
Swing back	20 secs.
Total	90 secs.

If there were no delays, it would be possible to handle 400 skip loads in 10 hrs. Usually, however, the loaders will cause more or less delay, so that it is safer to count upon what they will average rather than upon what the derrick can do. One derrick cannot serve a very long face, and the number of men that can be worked to advantage in a given space is always limited; hence I repeat that with a good derrick provided with a bull-wheel the derrick can ordinarily handle more stone than can be delivered to it by the men. The economic size of the skip load is entirely dependent upon the size of the hoisting engine, but a common size skip measures 5 x 6 ft. x 14 ins. deep. Where much work is to be done a contractor should never try to get along with a derrick not provided with a bull-wheel for "slewing" the boom, for the wages of two tagmen would soon pay for a new outfit.

Cost of Loading Blasted Rock With Steam Shovels.—A contractor who has never had experience in handling hard rock with steam shovels is almost certain to overestimate the probable output of a shovel loading rock. This is due very largely to the common tendency to think of all rock as being a material that differs only to moderate degree in hardness. On the Chicago Drainage Canal, two 55-ton shovels, each working two 10-hr. shifts a day for four months, averaged 296 cu. yds. per shovel per shift of solid rock (limestone) loaded into cars, although it is stated that one day one of the shovels loaded 600 cu. yds. of rock in 10 hrs. The limestone on the Chicago Canal did not break up into small pieces upon blasting (a condition that is essential to economic steam shovel work in rock), but it came out in large chunks, much of which had to be lifted with chains, instead of being scooped up by the dipper. When each separate rock must be "chained out" in this way, a steam shovel is really no better than a derrick, and is, in fact, not so good.

On a large contract near New York City, where the rock is a tough mica schist that breaks out in large chunks even with close spacing of holes, a 65-ton shovel with a 2¼-cu. yd. dipper averaged for several weeks about 280 cu. yds. of solid rock loaded in cars. Part of this rock was loaded with the dipper and part was chained.

On the Jerome Park Reservoir excavation in New York City the

rock is also a tough mica schist that blasts out in slabs even with heavy blasting. I am informed by Mr. R. C. Hunt, manager for Mr. John B. McDonald, contractor, that their 70-ton shovels loaded only 300 cu. yds. of solid rock per 10-hr. shift. Mr. Hunt says:

"This was in the gneiss rock (mica schist) of this vicinity. The fibrous nature of Manhattan and adjacent rocks causes it to break in such large and awkward shapes that the shovel cannot do itself justice. I therefore abandoned the use of shovels in the rock cuts and find that I can handle the rock with derricks more economically."

In thorough cut work on the Wabash Railroad, one 42-ton shovel loaded 240 cu. yds. of sandstone (solid measure) into dump cars in 10 hrs., as an average of a year's work; but about 10% of the working time was lost in breakdowns, etc.

In shale, or any friable rock that breaks up into pieces which readily enter the dipper, the output of a steam shovel is far greater than in hard rock such as we have been citing. Through the kindness of Mr. George Nauman, assistant engineer, Pennsylvania Railroad, I am able to give the output of several shovels working more than a year, in shale near Enola, Pa. Each shovel worked two 10-hr. shifts per day, six days in the week. In cut No. 1 there were nearly 2,000,000 cu. yds., of which 85% was rock. Of this rock a little was very hard limestone, some was blue shale nearly as hard, and most of it was red shale, somewhat softer. Excluding the first two months, the average output of each shovel per month of doubt-shift work was nearly 31,000 cu. yds., equivalent to 15,500 cu. yds. single-shift work. There were, on an average, four shovels at work, averaging 60 tons weight per shovel. The best month's output was 47,300 cu. yds. per shovel in August, 1903, and the poorest month (after work was well started) was 20,800 cu. yds. per shovel in February, 1904, working double shifts.

For costs of operating a steam shovel see the section on Earth Excavation.

Cost of Handling in Carts and Wagons.—Since a cubic yard of loose broken stone weighs about as much as a cubic yard of earth measured in place; and since, ordinarily, 1 cu. yd. of solid rock becomes 1.7 cu. yds. when broken, we may say that a team will haul about 60% as many cubic yards of solid rock per day as of earth. In other words, if the roads are such that 1 cu. yd. of packed (not loose) earth would make a fair wagon load for two horses, then 0.6 cu. yd. of solid rock would be a fair load. On page 121 the sizes of loads of earth that teams can haul are discussed, and it is only necessary to multiply the earth load as given there by 6/10 (or 60%) to find the equivalent load of solid rock.

Open-Cut Excavation.—This includes all rock excavation in open cuts (except trenches), where no special care is used to quarry the stone in certain sizes for masonry, but where explosives are used freely to break out the rock in sizes that can be handled with the appliances available.

Spacing Holes in Open-Cut Excavation.—A common rule is to

place the row of vertical drill holes a distance back from the face equal to the depth of the drill hole, and to place the drill holes a distance apart in the row equal to their depth. Another rule is to place the row of holes back from the face a distance equal to three-fourths their depth, and the same distance apart in the row. In stratified rock of medium hardness these rules may be followed in making the first experiments, but they will lead to serious error if applied to dense granitic rocks. In the limestone on the Chicago Canal, not much of which was loaded with steam shovels, the holes were usually 12 ft. deep and placed in rows about 8 ft. back of the face and 8 ft. apart. These holes were charged with 40% dynamite. In a railway cut through sandstone the holes were 20 ft. deep, 18 ft. back from the face and 14 ft. apart in the row. These holes were "sprung" three times, and each hole charged with 200 lbs. of black powder. In granite quarried for rubble for dam work, I have had to place the holes 4½ to 5 ft. back of the face and the same distance apart, the holes being 12 ft. deep, about 2 lbs. of 60% dynamite being charged in each hole. On railway work in the Rocky Mountains about the same spacing was found necessary in granitic rock that was to be broken up into chunks that a steam shovel could handle. In pit mining at the Treadwell Mine, Alaska, the holes are drilled 12 ft. deep, in rows 2½ ft. apart, the holes being 6 ft. apart in each row and staggered. This requires drilling 1.7 ft. of hole per cu. yd.

It is obviously impossible to lay down any hard and fast rule for the spacing of drill holes. In stratified rock that is friable, and in traps that are full of natural joints and seams, it is often possible to space the holes a distance apart somewhat greater than their depth, and still break the rock to comparatively small sizes upon blasting. In tough granite, gneiss, syenite and in trap where joints are few and far between, the holes may have to be spaced 3 to 8 ft. apart, regardless of their depth, for with wider spacing the blocks of stone thrown down by blasting will be too large to handle with ordinary appliances. The mica schist, or gneiss, of Manhattan Island is a good example of rock that requires close spacing of holes regardless of depth. I have seen holes in it 20 ft. deep and only 4 ft. apart.

The effect of spacing of holes upon the cost of excavation is best shown by tabulation of the feet of hole drilled per cubic yard excavated, as shown below:

Distance apart of holes, ft..	1	1.5	2	2.5	3	3.5	4	4.5	5
Cu. yds. per ft. of hole	.04	.08	.15	.23	.33	.45	.59	.75	.93
Ft. of hole per cu. yd.	27.0	12.0	6.8	4.3	3.0	2.2	1.7	1.33	1.08

Distance apart of holes, ft..	6	7	8	9	10	12	14	16	18
Cu. yds. per ft. of hole	1.33	1.80	2.37	3.00	3.70	5.32	7.25	9.52	12.05
Ft. of hole per cu. yd.	.75	.56	.42	.33	.27	.19	.14	.11	.08

Since in shallow excavations the holes can seldom be much further apart than 1 to 1½ times their depth, we see that the cost of drilling per cubic yard increases very rapidly the shallower the excavation. Thus an excavation 2 ft. deep, with holes 2 ft. apart, requires 4.3 ft. of drill hole per cubic yard, as against 0.42 ft. of hole per cu. yd. in a deeper excavation where drill holes are 8 ft. apart. Failure to consider this fact ruined one contractor on the Erie Canal deepening, where rock excavation was only 2 ft. deep. Furthermore, the cost of drilling a foot of hole is much increased where frequent shifting of the drill tripod is necessary.

By observing carefully the appearance of rocks in different localities it is possible in a short time to become tolerably proficient in the art of estimating the probable distance apart that holes must be drilled for the best effect with given charges of given kind of explosive; and with this end in view a young man should avail himself of every opportunity of studying prevailing practice in spacing drill holes in different localities.

Cost of Excavating Sandstone and Shale.—In excavating shales and sandstones of the coal measures of Pennsylvania, Ohio, Virginia, etc., I find that holes are usually 20 to 24 ft. deep, and spaced 12 to 18 ft. apart. On an average we may say that for every cubic yard of solid rock there is 0.1 lin. ft. of drill hole, when cuts are very wide, covering large areas of ground; but in thorough cuts for railroads it is not safe to count upon much less than 0.2 ft. of drill hole per cu. yd. The holes are almost invariably "sprung" with 40% dynamite to create chambers at the bottom of the holes, and then charged with black powder. As low as 1/50 lb. of dynamite per cu. yd. may be used for springing holes in shale, and as high as ½ lb. per cu. yd. in sandstone that is to be very heavily loaded. I should put the average at 1/20 lb. of dynamite per cu. yd. of shale, and 1/10 lb. per cu. yd. of sandstone. In granite ½ lb. per cu. yd. is common. A very common charge is 8 kegs (200 lbs.) of black powder per hole, or about 1 lb. per cu. yd. in side cuts, and 1½ to 2 lbs. per cu. yd. in thorough cuts, although as high as 3 lbs. per cu. yd. have been used in thorough cuts in sandstone where special effort was made to break up the rock to small sizes for steam shovel work. The drilling of the deep holes costs not far from 40 cts. per lin. ft. where drilling is done by hand with wages at 15 cts. an hour, and it may be as low as 12 cts. a lin. ft. if well drillers are used. Soda powder costs about 5 cts. per lb., and 40% dynamite 12 cts. per lb. We have, therefore, the following:

	Cts. per cu. yd.
Drilling 1/10 ft. to 2/10 ft. at 40 cts.	4.0 to 8.0
Dynamite 1/20 lb. to 1/10 lb.	0.6 to 1.2
Powder, 1 lb. to 2 lbs.	5.0 to 10.0
Total for loosening the rock	.96 to 19.2

The rock is commonly loaded with steam shovels, and it is not safe to count upon more than 500 cu. yds. of shale, or 250 cu. yds. of sandstone per shovel per 10-hr. shift.

Summary of Open Cut Data.—The two cost items that the inexperienced man should seek first to inform himself upon, are: (1) The number of feet of hole drilled per cubic yard in different kinds of rock; and (2) the number of pounds of explosive required per cu. yd. under varying conditions. Below I have given a summary of these items as applying to open cut work discussed in this book: the table does not apply to trenching, tunneling or other narrow work. Two examples are given for sandstones and two for shales, such as occur in the coal measures of Pennsylvania. In a thorough cut on railroad work, we have conditions that approach trench work, requiring more feet of hole and more powder than in open side cuts: hence the difference between Examples 5 and 6, 7 and 8. It will be observed that the large amount of drilling in Example 2 is due to the shallowness of the face or lift, and in Examples 9 to 12 it is due to the toughness of the rock.

I shall greatly appreciate further contributions of similar data from my readers, for use in future editions. The greater the number of records, such as those in this table, the better will readers be able to judge the range and the average for each class of rock.

Example.	Depth of Lift. Feet.	——Per Cubic Feet of Hole.	Yard.—— Lbs. of Black Powder.	Lbs. of Dynamite.	Grade of Dynamite.	Kind of Rock.
1	12	.40	...	.75	40%	Limestone, Chicago Canal.
2	6	1.00	...	.7	40%	Limestone, for crushing.
3	20	...	...	.37	50%	Limestone, for cement.
4	15	.43	...	26	50%	Limestone (holes sprung).
5	20	.10	1.0	.1	40%	Sandstone, side cut.
6	20	.20	2.0	.2	40%	Sandstone, thorough cut.
7	24	.08	.7	.03	40%	Shale, soft, side cut.
8	24	.20	1.5	.10	40%	Shale, hard, thorough cut.
9	16	1.36	...	.20	60%	Granite, for rubble.
10	12	1.33	...	.60	40%	Gneiss, New York City.
11	14	.63	...	.50	40%	Gneiss, New York City.
12	12	1.70	...	.67	40%	Syenite, Treadwell mine.
13	12½	.32	...	.44	52%	Magnetic iron ore.
14	14	.35	...	.20	75%	Trap, seamy.
15	16	1.00	...	.70	40%	Trap, massive.
16	25	.10	...	.80	50%	Granite, Grand Trunk Pacific (holes sprung, half the dynamite being used in springing).

By applying the preceding data as to unit costs of drilling, blasting, loading and hauling, it will be seen that rock excavation in open cuts ranges from about $0.50 to $1.50 per cu. yd., the lower price being for shales and sandstones and the higher price for cer-

tain granites and traps where holes are close spaced. It is a very common assumption that rock can be profitably excavated in open cuts at a contract price of $1 per cu. yd., but it will be seen that each case requires special study.

Cost of Excavating Gneiss, New York City.—I am indebted to Mr. John J. Hopper, civil engineer and contractor, for the following data. The work involved the excavation of 29,295 cu. yds. of gneiss (or mica schist) at One Hundred and Twenty-seventh street, New York City. The drilling of the main holes was done with four 3½-in. Ingersoll steam drills, and two "baby drills" were used for drilling block holes. The average height of the lifts was 12 to 15 ft., and the cut ranged from 2 to 63 ft. deep. Hand drillers and sledgers received $2 per 10-hr. day; laborers handling stone and loading wagons received $1.50; one of the machine drillers received $3, and the rest of the drillers received $2.75 a day. The baby drills were used only on the largest pieces thrown down by the blast; the ordinary sized stone from the blast was broken up by hand-drilled holes and by sledges to sizes suitable for building rubble foundation walls. A good deal of the stone was piled up during the winter until it could be sold. The drilling part of the plant cost $1,800; the boilers, derricks, hoists, etc., cost $1,080; 40% dynamite, costing 20 cts. per lb., was used. There were 18,433 lin. ft. of main holes drilled (not including block holes) in excavating 29,295 cu. yds. of solid rock. The total cost of the work, including the plant, cartage, sledging, etc., was $52,635. The itemized cost was as follows:

	Cts. per cu. yd.
Foremen and timekeepers	8.0
Engineers and drillers	10.9
Sledgers	38.3
Derrickmen and helpers	9.6
Labor, loading, etc.	24.7
Hand drillers	11.7
Blacksmith and helper	5.3
Hauling away in wagons	40.5
Explosives	9.8
Coal, coke, oil, etc.	6.0
Repairs to drills	1.0
Repairs to boilers, derricks, etc.	1.2
Total per cu. yd.	$1.67

Mr. Hopper informs me that in sound rock where 20-ft. holes could be drilled, a drill would average 70 ft. in 10 hrs.; but in shallow drilling the drills would frequently not average over 25 ft. each.

This is about as high a cost as need occur in open cut rock work of any kind, when wages are as above given.

See the section on Railways for cost of excavating gneiss for the New York Subway.

Cost of Gneiss Excavation for Dams.—Mr. J. Waldo Smith is authority for the statement that on several dam jobs done under his direction, near New York City, it had cost the contractors $1.65

per cu. yd. to excavate gneiss in open cuts, when wages of common laborers were $1.65 cts. per 10-hr. day. At Catona it had cost the contractors $3.50 per cu. yd. to excavate gneiss in the foundation for the dam, where no blasting was allowed. At Boontown, N. J., under similar conditions, it had cost $3.30 per cu. yd.

Summary of Costs on Chicago Canal.—The summary in Table X has been compiled by Mr. W. G. Potter. Common laborers in all cases receiving $1.50 for 10 hrs. work, all delays of 1 hr. or more being docked. Wages paid the other classes of men are given in my "Rock Excavation." The tabulated costs do not include shop repairs, but do include field repairs. The drilling item appears not to include the cost of drill sharpening. Plant interest and depreciation are not included either—a very important item where such expensive machines are used. Explosives include caps and dynamite, 12 cts. per lb. for the 40% dynamite being assumed to cover the cost of explosives. General expenses include superintendence, watchmen and incidentals.

TABLE X.—COST IN CENTS PER CU. YD. (SOLID).

	Channeling.	Drilling.	Explosives.	General Expense.	Pumping.	Conveying.	Pit Force.	Dump Force.	Total.
Brown Cantilever	3.9	4.1	8.0	3.2	1.0	3.6	14.6	0.0	38.3
Lidgerwood Cableway	3.7	3.8	8.4	2.7	1.0	3.6	15.6	0.0	38.8
Hullett-McMyler Derrick	3.9	4.0	7.4	2.5	1.8	5.3	18.3	0.0	43.2
Hullett Conveyor	4.1	3.7	8.5	3.8	1.2	6.2	21.4	0.0	48.9
Car Hoist No. 1	3.7	3.9	9.1	2.7	0.8	3.1	24.8	5.1	53.1
Car Hoist No. 2	3.9	3.6	8.9	3.2	0.9	1.2	22.9	2.3	47.1
Car Hoist No. 3	4.0	5.0	10.7	3.1	1.2	1.2	26.4	4.8	56.5

The descriptions of each of the foregoing machines and methods of excavating and transporting the rock (limestone) are given in my book on "Rock Excavation." The detailed cost of channeling per square foot is also given there.

Trenching in Rock.—This is a subject upon which practically nothing has ever been written. In consequence there is probably no class of rock work that is so often mismanaged; and, as a further consequence of the prevailing ignorance engineers' estimates of cost are often far too low and occasionally far too high. In city specifications for sewer trenching in rock it is customary to pay the contractor only for rock excavated within specified "neat lines." If he excavates beyond the "neat lines" he does so at his own expense. In sewer work the most common practice is to specify that payment will be made for a trench 12 ins. wider than the outside diameter of the sewer pipe, and 6 ins. deeper than the bottom of the pipe when the pipe is laid to grade. The most rational specification that I have seen for general use in rock trenching is as follows: "All trenches in rock excavation will be esti-

mated 2 ft. wider than the external diameter of the pipe and 6 ins. below the sewer grade."

Different rocks vary greatly in the way the sides and bottom shear off upon blasting. The sides of trenches in soft rocks can be cut off clean when the blast holes are properly loaded; but tough granites, traps, etc., leave jagged walls, generally involving excavation beyond the "neat lines" specified.

In excavating thin bedded, horizontally stratified rocks the drill holes seldom need to go much, if any, below the neat lines; that is, 6 ins. below the bottom of the pipe. But in excavating thick bedded and tough limestones and the like, it is generally necessary to drill 12 ins. below the bottom of the pipe. In tough granites, traps, etc., it is often necessary to drill at least 18 ins. below grade in order to leave no knobs or projections after blasting that would require breaking off with bull points and sledges. Obviously the shallower the trench the greater is the importance of making due allowance for this extra drilling.

The common practice in placing drill holes is to put down holes in pairs, one hole on each side of the proposed trench; and, if the trench is wide, one or more holes are drilled between these two side holes. However, it is not always necessary to drill the two holes (one on each side); but in narrow trench work, such as for a 12-in. water pipe, one hole in the middle of the trench will usually prove sufficient if it is made of large enough diameter to hold a heavy charge of dynamite. For example, in trenching for a 12-in. water pipe in New Jersey trap rock, holes were drilled in the center of the trench, 6 ft. deep, and 2 ft. apart. The result was a great saving in the cost of drilling per cubic yard.

Cost of Drilling and Blasting in Trenches.—Next to tunneling there is no class of rock excavation requiring so much drilling per cubic yard as does trench excavation. In granites, if shallow holes are drilled by hand, the holes are frequently spaced not more than 1½ ft. apart. If in a very narrow trench 1½ ft. wide two holes are drilled in a row, one on each side of the trench, and if the rows are 1½ ft. apart, we have two holes drilled in a square 1½ ft. on a side; that is, for every 2¼ cu. ft. of rock we must drill 2 ft. of hole, or 24 ft. of drill hole per cu. yd. If the cost of drilling is 25 cts. a foot, we have $\$0.25 \times 24 = \$6$ per cu. yd. as the cost of drilling alone. It is seldom, however, that such narrow trenching is done. Trenches for small pipes are usually 2½ to 3 ft. wide; two holes are usually drilled in a row, and rows are usually about 3 ft. apart. A trench 3 ft. wide with two holes in a row, and rows 3 ft. apart, requires 6 ft. of drilling per cubic yard. With drilling costing 50 cts. per ft., as it often does where hand drills are used in granite, the cost is then $3 per cu. yd. for drilling alone. Unless the job is too small to pay for installing a plant, hand drilling should never be used in trench work, because the drilling forms such a very large part of the cost.

In a trench 6 ft. wide in hard New Jersey trap rock three holes were drilled in a row, one close to each side and one in the middle,

and the rows were 3 ft. apart, thus requiring 4½ ft. of drill hole per cu. yd. of excavation. The drilling was done with steam drills at a cost of 30 cts. per lin. ft., for the holes were only 4½ ft. deep, the rock was hard, and the men slow, about 35 ft. being the day's work per drill. The contractor had to drill 1½ ft. below grade in this rock to insure having no projecting knobs of rock. While it cost $1.35 per cu. yd. to drill the 3½ ft. for which payment was made, to this must be added nearly 30%, or $0.40 per cu. yd., to cover the cost of drilling the extra 1 ft. for which no payment was received, making the total cost of drilling $1.75 per cu. yd. of pay material. About 2 lbs. of 40% dynamite were charged in each hole, making about 2.6 lbs. of dynamite per cu. yd. of pay material. The explosives thus added another $0.40 per cu. yd., making a total of $2.15 per cu. yd. for drilling and blasting.

In the same trap rock, where the trench was 8 ft. wide and 12 ft. deep, there were three holes in a row and rows were 4 ft. apart, requiring 2.53 ft. of hole per cu. yd. of pay excavation, plus 0.21 ft. of hole per cu. yd. of pay material to cover the cost of drilling the last 1 ft. of hole below the "neat line." Each drill averaged 45 ft. of hole in 10 hrs., and the cost was 23 cts. per ft. of hole; hence $\$0.23 \times 2.74 = \$0.63$ per cu. yd. was the cost of drilling. About 4 lbs. of 40% dynamite were charged in each hole, or 1.1 lbs. per cu. yd. of pay material, making the total cost 80 cts. per cu. yd. for drilling and blasting. A comparison of this cost of 80 cts. with the $2.15 above given brings out strikingly the fact that each problem of trench work must be considered in detail by itself.

In a city where the contractor must fire comparatively small shots in order to avoid accidents to buildings and suits for damages arising from "disturbing the peace," it is seldom possible to space the holes more than 3 or at most 4 ft. apart. In trenching in soft sandstone in Newark, N. J., where the trench was 14 ft. wide and 10 ft. deep, there were five holes in a row (the distance between holes being 3½ ft.) and rows were 4 ft. apart, making 2.4 ft. of hole per cu. yd. Each hole was charged with 4.12 lbs. of 40% dynamite, making practically 1 lb. per cu. yd. About half the dynamite was charged at the bottom of each hole, then tamping was put in, and the other half was charged up to about 2½ ft. below the mouth of the hole. Each steam drill averaged 90 ft. of hole per 10 hrs., making the cost of drilling 10 cts. per ft. of hole, or 24 cts. per cu. yd. Including the cost of dynamite and the placing of timbers over each blast, the cost of drilling and blasting was 40 cts. per cu. yd. This is probably as low a cost for breaking rock in a wide trench as can be counted upon under favorable conditions. In this rock there was no necessity of drilling below grade.

The cost of throwing rock out of shallow trenches or of loading it into buckets to be raised by the engine of a derrick, a locomotive crane or a cableway, is somewhat greater than the cost of handling rock in open cuts. A fair day's work for one man is 6 cu. yds.

of rock handled, when there is little sledging; but the output may be only 4 cu. yds. where there is a large amount of sledging to be done.

If cableways or derricks are used for hoisting the rock, bear in mind that they will be idle most of the time, for the drilling limits the output. With a given number of drills to a cableway, estimate the number of cubic yards of rock that the drills will break per day and divide this yardage into the daily cost of operating the cableway. Thus, in a trench 6 ft. wide, if the holes are 3 ft. apart, each cubic yard of rock requires 4½ ft. of hole, and each drill will break 13⅓ cu. yds. per day where 60 ft. of hole is a day's work. With four drills per cableway the daily output is $4 \times 13\frac{1}{3} = 53\frac{1}{3}$ cu. yds. The cableway would be capable of handling several times this output were it not limited by the drilling. Notwithstanding that all this seems self-evident, I have known more than one contractor to overlook the fact that the cost of handling rock from trenches is very much greater than in open cuts where holes are farther apart and where a few drills can keep a cableway busy.

I am indebted to Mr. F. I. Winslow for the following data on trench work in Boston, Mass.: For house sewer trenches, contractors are allowed 3 ft. width, and trenches for water pipe (16 ins. or less), 2½ ft. width. The rock is granite, and the drill holes are usually 3 ft. apart drilled along the center of the trench, but staggered a little off center. On small jobs hammer drills are used, one man holding and two striking. For a hole 10 ft. deep the starting bit is 2½ ins. and the finishing bit is 1¼ ins. diam. A drilling gang of three men averages 8 to 10 ft. of hole in 10 hrs., although in very soft rock 20 ft. may be drilled in 10 hrs. In a trench 10 ft. deep, the rock is usually excavated in two 5-ft. benches, but some contractors drill the full 10 ft. and take it out in one 10-ft. bench. Forcite containing 75% nitroglycerin is commonly used, ½ to 3 sticks being charged in a hole. Force account records for granite trenching, on jobs of less than 100 cu. yds. each, show that the average cost during the past 15 years has been $3.80 per cu. yd., including excavating and piling up the rock alongside the trench. The wages paid hand-drillers were $1.75 per 10-hr. day; and to laborers, $1.40 per day.

I am indebted to the Harrison Construction Co., of Newark, N. J., for the following information: In a sandstone trench about 6 ft. wide the holes were spaced about 3 ft. apart, thus requiring 4½ ft. of hole per cu. yd. In seamy rock, shallow holes 4 to 6 ft. deep were drilled, and from 2 to 3 sticks of 50% dynamite were charged, each stick being $1\frac{1}{2} \times 8$ ins. This is equivalent to 0.55 lb. per cu. yd. Where the rock was solid, the holes were drilled 8 to 10 ft. deep and the dynamite charge doubled.

Consult the sections on Water Works and on Sewers for further data on trenching.

Cost of Quarrying and Crushing Trap.—The following data relate to quarrying New Jersey trap rock and crushing it in gyratory crushers. The quarry face was 12 to 18 ft. high. The output of the following gang was 200 cu. yds. of crushed stone per 10-hr.

day, each cubic yard of crusher run product weighing 2,700 lbs., no piece being more than 2 ins. diameter. The weight of a solid cubic yard of this trap was 4,500 lbs., so that the voids in the crushed stone were 40%. Drill holes were spaced about 5 ft. apart.

	Per day.	Per cu. yd.
3 drillers at $2.75	$ 8.25	$0.041
3 helpers at $1.75	5.25	0.026
10 men barring out and sledging	15.00	0.075
14 men loading carts	21.00	0.105
4 cart horses	6.00	0.030
2 cart drivers	3.00	0.015
2 men dumping carts and feeding crusher	3.00	0.015
1 fireman for drill boiler	2.50	0.013
1 engineman for crusher	3.00	0.015
1 blacksmith	3.00	0.015
1 blacksmith helper	2.00	0.010
1 foreman	5.00	0.025
2 tons coal at $3.50	7.00	0.035
150 lbs. 40% dynamite at 15 cts.	22.50	0.113
Total	$106.50	$0.533

Interest, depreciation and repairs would add about $8 or $10 more per day, or 4 to 5 cts. per cu. yd., making a total of about 58 cts. per cu. yd. There was no earth stripping.

The stone was loaded into one-horse dump carts, the driver taking one cart to the crusher while the other cart was being loaded. The haul was 100 ft. The carts were dumped into an inclined chute feeding into a No. 5 Gates gyratory crusher. The stone was elevated by a bucket elevator and screened. All stone larger than 2-in. was returned through a chute to a small No. 3 Gates crusher to be re-crushed.

I should add that the trap rock was much seamed, so that upon blasting it was broken into tolerably small chunks, so that the cost of sledging was not high considering the small size of the crusher.

Cost of Crushing at Newton, Mass.—A. F. Noyes, City Engineer of Newton, Mass., gives the following cost data for the year 1891, on four jobs of crushing stone and cobbles for macadam. On jobs A and B the stone was quarried and crushed; on jobs C and D cobblestones were crushed. A 9 × 15-in. Farrel-Marsondon crusher was used, stone being fed in by two laborers. A rotary screen having ½, 1 and 2½-in. openings delivered the stone into bins having four compartments, the last receiving the "tailings" which had failed to pass through the screen. The broken stone was measured in carts as they left the bin, but several cart loads were weighed, giving the following weights per cubic foot of broken stone:

	Size			
	½-in. Lbs.	1-in Lbs.	2½-ins. Lbs.	Tailings. Lbs.
Greenish trap rock, "A"	95.8	84.3	88.3	91.0
Conglomerate, "B"	101.0	87.7	94.4	....
Cobblestones, "C" and "D"	102.5	98.0	99.6	....

A one-horse cart held 26 to 28 cu. ft. (average 1 cu. yd.) of broken stone; a two-horse cart, 40 to 42 cu. ft., at the crusher.

	Job A.	B.	C.	D.
Hours run	412	144	101	198
Short tons per hour	9.0	11.2	15.7	12.1
Cu. yds. per hour	7.7	8.9	11.8	9.0
Per cent of tailings	31.8	29.3	17.5	20.5
Per cent of 2½-in. stone	51.3	51.9	57.0	55.1
Per cent of 1-in. stone	10.2	....	....	....
Per cent of ½-in. stone or dust	6.7	18.8	25.5	23.4

	Job A.	B.	C.	D.
Explosives, coal for drill and repairs	$0.084	$0.018	......	......
Labor steam drilling	0.092	......	......	......
Labor hand drilling	....	0.249	......	......
Sharpening tools	0.069	0.023	......	......
Sledging stone for crusher	0.279	0.420	......	......
Loading carts	0.098	0.127	......	$0.144
Carting to crusher	0.072	0.062	$0.314*	0.098
Feeding crusher	0.053	0.053	0.033	0.065
Engineer of crusher	0.031	0.038	0.029	0.036
Coal for crusher	0.079	0.050	0.047	0.044
Repairs to crusher	0.041	......	......	0.011
Moving portable crusher	....	0.023	......	0.019
Watchman ($1.75 a day)	....	0.053	0.022	0.030
Total cost per cu. yd	$0.898	$1.116	$0.445	$0.447
Total cost per short ton	0.745	0.885	0.330	0.372

*Loading and hauling in wheelbarrows.

NOTE.—"A" was trap rock; "B" was conglomerate rock; "C" and "D" were trap and granite cobblestones. Common laborers on jobs "A" and "D" were paid $1.75 per 9-hr. day; on jobs "B" and "C," $1.50 per 9-hr. day; two-horse cart and driver, $5 per day; blacksmith, $2.50; engineer on crusher, $2 on job "A," $2.25 on "B," $2.00 on "C," $2.50 on "D"; steam driller received $3, and helper $1.75 a day; foreman, $3 a day. Coal was $5.25 per short ton. Forcite powder 11½ cts. per lb.

Cost of Quarrying and Crushing Quartzite.—Mr. W. G. Kirchoffer gives the following data on the cost of quarrying and crushing quartzite for macadam, in 1903, at Baraboo, Wis. The plant was a municipal plant operated by day labor, and the costs were somewhat higher than under contract work. The crusher was a No. 3 Austin jaw crusher, 12 x 16-in. opening. Three sizes of screen holes in the rotary screen were used: ¾-in., 1¾-in. and 2½-in. The first cost of the plant was as follows, in 1901:

Crusher	$ 900
Bins	108
Steam drill	218
Small tools	108
	$1,334

The output of the crusher by years has been:

	Year 1901.	1902.	1903.
Total output, cu. yds.	1,920	3,700	4,883
Days worked	47	70	88
Output per day, cu. yds.	41	53	55½

In the year 1901, about 10% of the stone was screened out and

thrown away. The wages paid per 10-hr. day were: Laborers, $1.50; quarrymen, $1.75; drill-runner, $2; engineman and engine, $3.50. The stone was measured in wagons built to hold just 1⅓ cu. yds., by weight, 3,900 lbs., and the following costs for 1903 are based upon wagon measurement of the stone:

	Per cu. yd.
Quarry rent	$0.0207
Labor quarrying, including foreman	0.3200
Labor crushing	0.1980
Tools	0.0148
Dies for crusher	0.0636
Dynamite (60% at 25 cts. per lb.), caps and fuse	0.0910
Rent of engine and wages of engineman	0.0635
Fuel for engine, $4.60 per ton	0.0477
Oil and waste	0.0033
Hauling water and supplies	0.0499
Supplies	0.0137
Superintendent of crusher	0.0476
Depreciation of plant	0.0736
Total	$1.0074

The cost of hauling 2½ miles to the street was 50 cts. per cu. yd., wages of team and driver being $3 a day.

The cost of the macadam pavement, including stone, hauling, grading, spreading stone, claying and rolling, has been a little less than 50 cts. per sq. yd. The macadam was 8 ins. thick at the center and 6 ins. at the gutters, measured after rolling.

Cost of Quarrying and Crushing Limestone for Macadam.—The cost of operating a small quarry, and crushing with a portable or semi-portable crusher is obviously much higher than where a large plant is used. For some time to come the greater part of road-metal crushing will be done with small plants, under conditions such as I am about to describe, and at costs not far differing from those that will be given.

In quarrying limestone, where the face of the quarry was only 5 to 6 ft. high, and where the amount of stripping was small, one steam drill was used. This drill received its steam from the same boiler that supplied the crusher engine. The drill averaged 60 ft. of hole drilled per 10-hr. day, but was poorly handled and frequently laid off for repairs. The cost of quarrying and crushing was as follows:

Quarry.

1 driller	$ 2.50
1 helper	1.50
1 man stripping	1.50
4 men quarrying	6.00
1 blacksmith	2.50
⅓ ton coal at $3	1.00
Repairs to drill	.60
Hose, drill steel and interest on plant	.90
24 lbs. dynamite	3.60
Total	$20.10

Crusher.

1 engineman	$ 2.50
2 men feeding crusher	3.50
6 men wheeling	9.00
1 bin man	1.50
1 general foreman	3.00
⅓ ton coal at $3	1.00
1 gallon oil	.25
Repairs to crusher	1.50
Repairs to engine and boiler	1.00
Interest on plant	1.00
Total	$24.25

Summary—

	Per day.	Per cu. yd.
Quarrying	$20.10	$0.34
Crushing	24.25	0.41
Total for 60 cu. yds.	$43.85	$0.75

The "4 men quarrying" barred out and sledged the stone to sizes that would enter a 9 x 16 in. jaw crusher. The "6 men wheeling" delivered the stone in wheelbarrows to the crusher platform, the run plank being never longer than 150 ft. Two men fed the stone into the crusher, and a binman helped load the wagons from the bin, and kept tally of the loads. The stone was measured loose in the wagons, and it was found that the average load was 1½ cu. yds., weighing 2,400 lbs. per cu. yd. There were 40 wagon loads, or 60 cu. yds. crushed per 10-hr. day, although on some days as high as 75 cu. yds. were crushed. The stone was screened through a rotary screen, 9 ft. long, having three sizes of openings, ½-in., 1¼-in. and 2½-in. The output was 16% of the smallest size, 24% of the middle size, and 60% of the large size. All tailings over 2½ ins. in size were re-crushed.

It will be noted that the interest on the plant is quite an important item. This is due to the fact that, year in and year out, a quarrying and crushing plant for roadwork seldom averages more than 100 days actually worked per year, and the total charge for interest must be distributed over these 100 days, and not over 300 days as is so commonly and erroneously done.

The cost of stripping the earth off the rock is often considerably in excess of the above given cost, and each case must be estimated separately. Quarry rental or royalty is usually not in excess of 5 cts. per cu. yd., and frequently much less.

The dynamite used was 40%, and the cost of electric exploders is included in the cost given. Where a higher quarry face is used the cost of drilling and the cost of explosives per cu. yd. is less. Exclusive of quarry rent and heavy stripping costs, a road contractor should be able to quarry and crush limestone or sandstone for not more than 75 cts. per cu. yd., or 62 cts. per ton of 2,000 lbs., wages and conditions being as above given.

The labor cost of erecting bins and installing a 9 x 16 jaw crusher, elevator, etc., averages about $75, including hauling the plant two or three miles, and dismantling the plant when work is finished.

The first cost of a quarrying, crushing and macadam road building plant is given in following paragraph.

Price of Road Building Plant.—The following gives the first cost of a typical portable plant for quarrying and crushing rock, grading, hauling and building a macadam road:

Crusher Plant—	
1 jaw crusher (9 x 15 in.), with rotary screen..	$1,100
Portable bins	200
Engine to drive crusher (15 HP.)	200
Boiler on wheels (20 HP.)	600
Total crusher plant	$2,100
Quarry Plant—	
2 steam drills at $250	$ 500
Steam pipe, waterpipe, etc.	150
Quarry and blacksmith tools	150
Steam boiler (15 HP.)	400
Total quarry plant	$1,200
Road Plant—	
6 dump wagons for hauling stone at $125	$ 750
6 dump wagons for grading at $125	750
2 leveling scrapers at $100	200
12 wheel scrapers at $50	600
12 drag scrapers, shovels, picks, etc.	150
1 steam roller	2,500
2 sprinkling wagons at $300	600
Gasolene pump and portable water tank	500
Total road plant	$5,850
Grand total	$9,150

Cost of Jaw Crusher Renewals.—Mr. Thomas Aitken gives the following data as to costs in England, for a 9 x 16-in. jaw crusher (Baxter) whose first cost complete was $1,500. The crusher averaged 66 long tons of trap per 10-hr. day.

	Life in tons crushed.	First cost of part.	Cost per long ton, cents.
Upper jaws (reversible)	8,000	$11	0.13
Lower jaws (reversible)	4,000	11	0.26
Top rotary screen (plates ¼ in.)	24,000	30	0.12
Lower rotary screens	48,000	23	0.04
Elevator belt (5 ply; 26 ft. long), plates, etc.	32,000	60	0.18
Elevator buckets (25)	8,000	10	0.12
Toggles and bearings, etc.	8,000	14	0.16
Total			1.01

This crusher has a capacity of 80 tons (of 2,240 lbs.) per day, is mounted on wheels, and has two short rotary screens (one above the other) mounted on the same framework with the crusher itself, and it carries a very small bin, also on the same frame. The machine is entirely self-contained, and thus is readily portable. Our American practice is to have large separate bins (sometimes on wheels), and consequently a much longer elevator. While the first cost of our American crushers of the same size is also about $1,500 complete, our repair parts will average nearly double the cost given by Mr. Aitken for English conditions.

Aitken states that 1 hp. (nominal) for each ton crushed per hour will drive the Baxter crusher, but it is noteworthy that he gives a coal consumption of 720 lbs. per day, which indicates far more than 8 hp.

Cost of Quarrying and Crushing Limestone, Missouri.*—Mr. Curtis Hill gives the following relative to work done by contract in 1908 for the Missouri Highway Department. The stone was a hard, bluish gray limestone. Two quarries were opened up near the road, and a total of 13,000 cu. yds. of crushed stone produced.

		Cost per cu yd.
Quarrying—		
Foreman and timekeeper, at	$0.40	$0.056
Drillers (hand), at	.17½	.018
Drillers (steam), at	.17½	.031
Laborers, at	.17½	.224
Teams, at	.35	.021
Powder, lbs. at	.10	.059
Caps, at	.10	.002
Fuse, ft., at	.01	....
Watchman, at	.15	.017
Water boy, at	.10	.012
Quarry rent, at	...	.030
Total quarrying		$0.472
Crushing—		
Foreman and timekeeper	.40	.064
Laborers	.17½	.121
Engine and engineman	.40	.067
Watchman	.15	.007
Total crushing		$0.259
Grand total		$0.731

This does not include plant interest, repairs and depreciation, nor insurance of men.

The stone was screened through three sizes of hole, ½, 1½ and 3-in.

The crusher was a portable jaw crusher, and its output was 65 cu. yds. per 10-hr. day.

The organization was about as follows:

1 quarry foreman.
1 steam driller.
1 hand driller (¾ time).
8 laborers, quarry.
1 team (½ time).
1 water boy.
1 watchman.
1 crusher foreman.
4 laborers at crusher.
1 engineman on crusher.

Cost of Crushing and Hauling Cobblestones.†—Mr. W. A. Gillette is author of the following:

It may be of interest to builders of macadam roads or crushers

*Engineering-Contracting, Aug. 4, 1909.

†Engineering-Contracting, April 28, 1909.

of stone to know how cheaply the work can be done with a good small plant and when the supervision of the plant is intelligently administered. My experience in the above class of work leads me to believe that few plants of a capacity similar to the one which shows the output I will give below are giving such satisfactory results. The plant in question is owned by the City of Ventura, Cal., and the rock is used in the construction of petrolithic macadam.

The engineering of the entire work has been done by J. B. Waud, and Mr. James M. Montgomery is the contractor. Mr. Montgomery has an exceptionally fine lot of stock, and the organization of his work is about as near perfection as it could be.

While looking over the work at Ventura the writer took occasion to make an inquiry regarding the cost per cubic yard for stone delivered on the street. This question was brought about from the fact that the work was being done at an exceptionally low cost, and it was hard to understand just why the cost was so much less than that of other similar construction.

I was told that the cost of the rock delivered on the street was something less than 50 cts. per cu. yd. It hardly seemed possible, when it was known that the average haul from the crusher to the work was about a mile, while the tough cobbles which are being crushed are gathered on the ocean beach and hauled in 1½-cu. yd. dump wagons to the crusher, a distance of about 1,500 ft., two teams with two wagons and drivers being used for this purpose.

Eight laborers are used to load the cobbles into the wagons; three men and the foreman do the work at the crusher and bins. The power to operate the crusher is electricity.

Five teams and drivers with dump wagons holding 2 cu. yds. each haul the crushed stone to the streets.

On this particular day all of the crushed stone was hauled ¾ mile and the screenings were hauled 1¼ miles. The wagons were heaped up so that they reached the street more than full. A good part of this haul was over very rough roads, so the rock was well settled in the wagon boxes.

The wages paid are as follows:

Two-horse team, wagon and driver, $4.50 for 9 hrs.

Foreman, $4 per day.

Laborers, $2 per day.

The following is an itemized statement of the 9-hr. day's work:

One foreman, at $4.00 per day	$ 4.00
Eleven laborers, at $2.00 per day	22.00
Two teams hauling cobbles to crusher, at $4.50 per day	9.00
Five teams hauling crushed stone to street, at $4.50 per day	22.50
Electric power, 67 kw. hours, at 3 cts.	2.00
Engine oil	1.00
Total	$60.50

The total output for a large day's run was 132 cu. yds., as measured in the wagon boxes at a cost of $60.50, or 45.8 cts. per cu. yd.

delivered on the street, exclusive of plant interest and depreciation. The plant cost $3,000. It consists of a No. 3 Austin gyratory crusher, having two 8½ x 24-in. openings, driven by an electric motor.

Where the rock was crushed so that all of it would pass through a 2-in. ring the average output was 90 cu. yds. per 9-hr. day, or 67 cts. per cu. yd. for labor, hauling and power.

The cost of interest and maintenance of plant is not included.

Cost of Quarrying and Crushing Trap, and Ballasting, D., L. & W. Ry.*—Mr. Lincoln Bush is author of the following:

Early in 1905 the D. L. & W. Ry. Co. acquired by purchase near Boonton, N. J., a granite quarry and crusher plant, together with other equipment in the way of cars, machinery, etc., that were utilized by a contractor in connection with the construction of a large masonry dam for a reservoir. This work having been completed by the contractor, the Lackawanna Railroad Company acquired about 3 miles of railroad running from its main line to the quarry plant, together with about 56 acres of ground, tracks at crusher plant, etc. In adapting this plant to our use and rearranging the tracks and crusher layout to meet our requirements, we expended at the outstart $21,904.33, and sold from the contractor's outfit certain equipment not required by us, which sale netted us $18,159.31, making the net cost to us of the quarry and plant at the time we started operating the crusher $26,245.02.

The material obtained from this crusher plant is a very good quality of New Jersey granite, weighing 2,795 lbs. per cu. yd. of crushed stone.

The quarry was well opened up when we acquired it from the contractor, and the face of the quarry has a depth of from 20 to 60 ft. and a length of about 2,200 ft. The stripping on top of the quarry will average about 2½ ft.

The crusher machinery was manufactured by the Allis-Chalmers Co., and consists of one No. 8 and one No. 6 crusher, with a large bucket conveyor for conveying the broken stone from the crusher to the screens. There is one large 48-in. diameter screen, consisting of three sections, each 4 ft. in length, with ringings from ½ in. to 2½ ins. in diameter and a dust jacket for separating the materials. Materials which pass through the ½-in. ringing are not used for track ballast. The ballast product is conveyed on a Robins belt conveyor and deposited into a system of bins; the finer material and dust pass directly over the dust jacket into the dust bin.

The percentage of fine materials, i. e., dust and ¼-in. stuff, runs from 12% to 14% of the total output.

The grades of tracks at the crusher plant are so arranged as to handle the cars after being placed by gravity.

There is a powder magazine located on the property which has a storage capacity for about 10 tons of powder and explosives.

**Engineering-Contracting*, March 24, 1909.

There is also a water system for the boilers and a sprinkling plant to keep down the dust.

The maximum grade of the track connecting our main line with the quarry is 3% ascending to the quarry, and in handling our ballast we have been utilizing a locomotive which will handle 14 empty Rodger ballast cars up this 3% grade.

The larger part of the stone is handled from the quarry to the crusher plant by means of a derrick system, the face of the quarry being located quite close to the crusher plant. We have in use 6 large derricks with 90-ft. masts, which, with 6 hoisting engines operated in connection with the derrick system, handle the stone in large stone boxes. The stone is quarried from the top of the face by a stepping system.

To pass into the No. 6 crusher the stone has to be broken up in sizes from 16-in. to 20-in. The breaking of the material is done with a system of block hole drills, placing holes from 6 ins. to 12 ins. apart, depending upon the size of the stone to be broken. We use from 3 to 6 block hole drills per day in breaking up the larger stone and some of the smaller stones are sledged instead of being block holed.

In addition to the derrick system at this plant we also have a car system, by means of which cars are loaded with stone from the quarry are dropped by gravity to the crusher. These cars have from 12 to 16 cu. yds. capacity, and when the cars reach the crusher plants are dumped by one of the derricks. The bottom of these cars is constructed of wood and metal, with a chain attached, and the false bottom of the car is picked up on one end by the derrick, and the stone dumped by this means without manual handling. After the cars have been dumped at the crusher they are returned to the quarry by a haulage system, operated by a hoisting engine. The stripping from the top of the quarry is disposed of by piling it back from the face of the quarry.

In operating the quarry and crusher we have employed an average of 125 men, including rock men, drill men, engineers, mechanical men and laborers required at the quarry and crusher. We employ two blacksmiths for handling the drill work and a pipefitter for taking care of the steam-pipe system and steam drills. One mechanical foreman with the necessary help has charge of the crushing plant and one general foreman has charge of the quarry. One engineer handles the engine in the crusher plant and one fireman does the firing.

We utilize a 150-hp. boiler for generating steam for the drills, and in addition to this we have two 150-hp. boilers for furnishing the balance of power for the derricks and at the crushers.

We started operating the quarry and crusher plant in May, 1905. The plant was shut down on January 15, 1906, and operations resumed in March, 1906. The detailed statements of the cost of quarrying and crushing stone at this plant have been carefully kept and are reliable as to the cost as well as to output. The cost includes the quarrying and crushing, and includes the material loaded on cars at the bins.

The costs were as follows:

Month and Year.	Output, cu. yds.	Average cu. yds. per day.	Cost per cu. yd. for quarrying, cts.	Cost per cu. yd. for crushing, cts.	Cost per cu. yd. quarrying and crushing.
May, 1905......	6,637	246	46.2	8.9	55.1
June, 1905	7,048	271	50.6	7.6	58.2
July, 1905	6,267	241	55.9	6.6	62.5
August, 1905....	8,722	323	51.1	5.3	56.4
September, 1905.	7,017	270	55.2	6.6	61.8
October, 1905...	6,321	243	56	7.2	63.2
November, 1905.	6,219	235	47.9	5.8	65.1
December, 1905.	5,882	249	57.5	7.6	53.7
January, 1906...	3,233	269	39.2	6.3	45.5
April, 1906	7,516	301	51.5	6.7	66
May, 1906	11,594	429	40	5	50
June, 1906	10,622	409	47	5	52
July, 1906	10,894	436	45.5	6	52.5
August, 1906....	10,183	377	49	6	55
Average		307	49	6.5	55.5

The average cost for the four months of May to August, 1906, was as follows:

	Per cu. yd. cts.
Quarrying:	
Labor	38.4
Supplies	6.6
Total quarrying	45.0
Crushing:	
Labor	3.5
Supplies	2.5
Total crushing	6.0
Grand total	51.0

These costs do not include interest and depreciation of plant, but do include all other items, even to current repairs.

We have used the crushed stone from this plant at various points along our line on the Morris and Essex Divisions, and during the present season we put on a ballast gang for ballasting a 4½-mile section of double track located between Hopatcong and Wharton, N. J.

In handling the ballast on this 4½-mile section we had an average of 31 laborers at 14 cts. per hour per hay of 10 hrs. and one foreman at $75 per month. In addition to the regular ballast gang we had 8 section laborers on the 4½-mile section that were employed in digging out, changing ties, placing drain tile and filling for changes in alignment and easement curves.

The amount of ballast used on the 4½-mile section of double track was 28,458 cu. yds., or an average of 6,324 cu. yds. per mile of double track. The average distance which the ballast was hauled from the crusher to the section ballasted was 13 miles. On the 4½-mile section of track ballasted there was a total length of curve line of 1.56 miles and a total length of tangent

of 2.94 miles. We used in this work 24 Rodger ballast cars, and in figuring the cost of transportation the cars were placed at a value of $600 each. Our records show a cost of 5⅛ cts. per cu. yd., covering transportation charges, interest on the Rodger ballast cars valued at $600 each at 5%, plus interest at 5% on the net investment of the quarry and crusher plant. The cost for quarrying, crushing and loading cars at the crushing plant was 55 cts. per cu. yd.; the cost of placing ballast under track, including lining, surfacing and dressing, was 20½ cts. per cu. yd., making a total cost per cubic yard of the ballast in the track of 81 cts. for the 4⅛-mile section above described.

On the west end of our Buffalo Division we have an accurate record of the cost of 27,120 cu. yds. of crushed limestone ballast put in on a stretch of double track during the season of 1906. For this work we purchased the crushed stone delivered to us in our own Rodger ballast cars at an average cost of $0.6017 per cu. yd., and received an average of 222 cu. yds. per day, the quarry being located on our own lines. Thirty Rodger ballast cars were used for this work and the average haul was 13.4 miles. The ringing used in preparing this ballast was from ¾ in. to 2½ ins. diameter and the stone weighed 2,410 lbs. to the yard. As above stated, we received on an average 222 cu. yds. per day, and a larger quantity per day would have reduced the cost per yard somewhat. In comparing this cost with the cost of ballasting with materials obtained from the Boonton crusher plant, it will be noted that the ballast on cars from the Boonton plant cost practically 5 cts. per cu. yd. less than the material used on the Buffalo Division. The work on the Buffalo Division cost a total of 88.1 cts. per cu. yd., in track, which cost included the material, engine service, labor, tie renewals and spacing, and interest on ballast car equipment.

Cost of Quarrying, Crushing and Ballasting, and Life of Ballast.*—From tests of trap and other rocks, it is seen that a material saving can be effected by the use of trap for ballast purposes. Less stone will be required to maintain the track, and it can be used in smaller sizes, as its higher percentage of hardness and toughness will insure less breaking under traffic and tamping. Figures taken from comparison of line and surface in trap with that in stone whose quality is about the same as limestone, show that line and surface cost approximately $20 less per mile in trap than in limestone.

Cost of Plant.—From published figures, the cost of building a plant of 1,000 tons daily capacity, and its cost of operation to quarry, is as follows:

Capacity, 1,000 tons daily	300,000 tons annually
900 cu. yds. trap per 10-hr. day	270,000 cu. yds. annually
Crushers, 4, 250-ton Farrel, at $1,250	$ 5,000
Engines, 4, 60-hp., 14 x 12, at $500	2,000
Foundations	100
Belting, 13-in., 200 ft., at $2.75	550

*Engineering-Contracting, Sept. 1, 1909, abstract of a report to the Am. Ry. Eng. and Mn. of Way Assoc.

Boilers, 2, 200-hp. and setting	7,500
Steam fittings	4,000
Boiler house	2,500
Engine house	1,500
Stack	2,000
Scales, 60-ft., including foundations and timber	1,225
Bins	600
Elevators with platforms, 4, at $1,500 (for tailings)	6,000
Pump for water supply, 5,500 gals. per hour	200
Tank, 50,000 gals.	1,200
Steam drills, with tripods connecting hose, 20, at $245	4,900
Screens, rotary, 54-in., 4, at $950	3,800
Small tools, forges, bars, wedges, hammers, etc.	1,200
Derrick, small stiff leg	150
Total	$44,425
Contingencies, 8%	3,553
	$47,978
Land, 50 acres, at $150 per acre	7,500
Cable railway and dump cars for haul to crusher, this being a varying item as quarry is worked	5,000
Total cost of quarry	$60,478

COST OF OPERATION OF QUARRY PLANT.
Capacity, 270,000 Cu. Yds. Per Annum.

18 drillers, at $3 per day, 300 days		$ 16,200
18 helpers, at $1.75 per day, 300 days		9,450
3 blacksmiths, at $3 per day, 300 days		2,700
50 bar sledgers, at $1.75 per day, 300 days		26,250
60 car loaders, at $1.75 per day, 300 days		31,500
8 crusher men, at $1.75 per day ,300 days		4,200
1 quarry boss, at $5 per day, 300 days		1,500
1 fireman, at $2.50 per day, 300 days		750
1 engineer, at $3 per day, 300 days		900
4 bin men, at $1.75 per day, 300 days		2,100
1 scale man, at $2 per day, 300 days		600
1 carpenter, at $3 per day, 300 days		900
10 laborers, at $1.75 per day, 300 days		5,250
1 clerk, at $750 per year		750
Fuel, 2,700 tons of coal, at $2.70		7,290
Oil, waste, etc.		500
Dynamite, .7 lb. per cu. yd., 270,000 cu. yds.—189,000 lbs., at 15 cts.		28,350
Drill repairs—		
1 machinist, at $4		1,200
1 helper, at $2.50		750
Supplies at $1.25 per month per drill		270
Blacksmiths included above		...
Total		$141,410
4% on first cost of plant	$2,418	
10% depreciation on machinery, except crushers	2,160	
16⅔% depreciation on crushers	833	
		5,411
		$146,821
Contingencies, 8%		11,750
		$158,571

This shows a cost per yard of 59 cts.

With this figure, the estimated saving shown from the use of trap rock (Gabbro) over limestone now used, from Martinsburg quarry, on the Baltimore & Ohio Railroad, in a 16-mile section, double track, or 32 miles of single track, based on changing the

entire ballast in a five-year period, and using 2,200 cu. yds. of trap rock per mile, 8-in. under the tie, would be as follows:

Gabbro—	
Quarrying	$0.60
Placing in track	.15
Average haul, 18 miles, at .001	.02
Total estimated cost per cu. yd.	$0.77
Limestone—	
Quarrying	$0.55
Screenings, 33%	.18
Placing in track	.15
Average haul, 98 miles, at .001	.10
Total actual cost per cu. yd.	$0.98

SUMMARY.

Limestone, 14,080 cu. yds., at 98 cts.	$13,798.40
Gabbro, 14,080 cu. yds., at 77 cts.	10,841.60
Saving per year during ballasting, due to use of trap rock	$ 2,956.80

As to saving in maintenance 300 cu. yds. of trap rock per mile per year will maintain track as efficiently as 400 cu. yds. of limestone.

32 miles single track × 400 cu. yds. limestone × 98 cts.	$12,544
32 miles single track × 300 cu. yds. trap rock × 77 cts.	7,392
Saving per year due to use of trap rock after track is fully ballasted	$ 5,152
Saving in line and surface, 32 miles, at $20	640
Total saving per year after track is fully ballasted	$ 5,792

The saving in maintenance labor during ballasting would be:

1st year	....	
2d year, 6.4 miles × $20	$128	
3d year, 12.8 miles × 20	256	
4th year, 19.2 miles × 20	384	
5th year, 25.6 miles × 20	512	
Total five years labor saving during ballasting (maintenance)		$ 1,280.00
Five years saving in first cost, due to use of trap rock		14,784.00
Total five years saving during ballasting		$16,064.00
Average saving per year during ballasting		3,212.80
Saving per year after fifth year		5,792.00

These figures give an idea of the savings which may be effected by going into such questions thoroughly, and getting accurate data. Such comparisons may be worked up for stone, gravel and cinder, and estimate made which will show a railroad management how far they are justified in going into such economies.

[There is clearly an error in the assumption that it will take anything like 300 or 400 cu. yds. of stone yearly to maintain a mile of ballasted track. See the section on Railways for cost of maintenance of way.]

Cost of Crushing with City Plant, Boston.— In *Engineering-Contracting*, Aug. 11, 1909, is a long abstract from the Metcalf & Eddy report to the Boston Finance Commission, of which the following is only a meager abstract:

The crusher plant occupies an area of 570,000 sq. ft., pur-

chased in 1882 for $30,000 and having an assessed value in 1907 of $79,800. The tract is used in part for other than quarrying and crushing purposes. The plant consists mainly of a 30 x 13-in. Farrel crusher, a 72 x 16-in. Atlas engine, a 66-in. x 17-ft. tubular boiler, the usual elevators, bins, extra parts and tools, and of three large and one baby steam drills. The estimated cost of the plant was $16,653; interest was calculated at 4% and depreciation at 6.75% annually, which gives an amount of $1,791, which in the costs following was applied on a monthly basis. The charge for steam drills is based on a rental of 50 cts. per working day.

Force Employed.—The force employed, with wages, was in general as follows:

Labor at Ledge:	Per day.
1 sub-foreman, at $3.50	$ 3.50
1 blacksmith, at $3	3.00
1 blacksmith's helper, at $2.25	2.25
3 steam drillers, at $2.25	6.75
3 steam drillers' helpers, at $2.25	6.75
10 stone breakers, at $2.25	22.50
5 hand drillers, at $2.25	11.25
1 powderman, at $2.25	2.25
9 loaders, at $2.25	20.25
Total	$ 78.50
Labor at Crusher:	
1 engineer, at $3.50	$ 3.50
1 fireman, at $3.25	3.25
1 weigher, at $3.50	3.50
1 oiler, at $2.25	2.25
3 feeders, at $2.25	6.75
1 pitman, at $2.25	2.25
Total	$ 21.50
Teaming:	
6 single teams, at $3.50	$ 21.00
Total	$121.00

The force consisted largely of men who were in some degree skilled in rock work. The majority of the men were young and all were vigorous and skilled to such an extent that the force as a whole was skillful and efficient. There was a marked lack of interest on the part of some of the employes, which undoubtedly had its effect in reducing the amount of work done considerably below the amount which would be done under contract conditions; on the other hand it should be stated that some of the men took a lively interest in the work and did their full duty.

In this connection it should be noted that the capacity of the bins being only about 400 tons, they were sufficient only for about 2½ days output of the crusher as it was operated. The normal capacity of the crusher is claimed by the manufacturers to be about 250 tons per day, while the maximum output for any one day during this test was 225 tons.

During three weeks in July, three drills were operated, but this was found to be inadvisable because the force of laborers was unable to handle the rock as fast as it was blown out.

The duration of this test was from May 28 to September 10, 1908, inclusive. The work accomplished during the test may be summarized as follows:

Work Done:

Stripping removed (a large part of the stripping had been done prior to the beginning of this test and is not included herein)	384 tons
Holes drilled (2¾-in. diameter) by steam drill	4,160.1 ft.
Unbroken stone on hand at beginning of test	none
Unbroken stone on hand at expiration of test (estimated)	200 tons
Broken stone ready for crusher at expiration of test	none
Broken stone on hand at expiration of test	none
Total output of crushed stone during test:	
Dust 1,970 tons (22%)	
Stone 6,983 tons (78%)	
Total	8,953 tons

	Total cost.	Cost per ton.
Labor:		
Supervision (foreman):		
Quarrying and breaking, 90%	$ 253.58	$0.028
Crushing, 10%	28.17	0.003
Buildings	93.36	0.010
Installing drilling plant	77.21	0.009
Removing and storing drilling plant	18.00	0.002
Operating drills	453.95	0.051
Furnishing steam for operating steam drills	114.16	0.013
Cleaning rock for drills and moving same	100.66	0.011
Blacksmith on ledge tools and pipe fittings	382.57	0.043
Blasting and care of explosives	182.29	0.020
Breaking stone	1,362.42	0.152
Hand drilling (block holes)	515.55	0.058
Loading stone	1,010.87	0.113
Removing and loading stripping	124.00	0.014
Weighing stone	181.57	0.020
Weighing stripping	19.67	0.002
Feeding crusher	331.61	0.037
Crusher operation (engineer, fireman, oiler and pitman)	539.74	0.060
Crusher repairs	55.54	0.006
Absent with pay	27.58	0.003
Holidays	705.75	0.079
Teaming:		
Buildings	4.50	0.001
Drilling plant	3.00	0.000
Hauling stone to crusher	929.28	0.104
Hauling stripping	111.47	0.012
Hauling product to pile	281.15	0.031
Total labor and teaming	$7,907.65	$0.882

Material, Rental, Interest and Depreciation: Ledge Rock:	Cost.	Cost per ton on output.
Blacksmith's coal, 1.32 tons	$ 5.54	$0.001
Battery repairs	4.86	0.001
Dynamite, 75%, 1¼ in., 1,060 lbs.	214.60	0.024
Dynamite, 75%, 1¼ in., 641 lbs.	129.80	0.015
Dynamite, 60%, 1¼ in., 356 lbs.	63.22	0.007
Black powder, 6 lbs.	0.66	.....
Connecting wire, 50 ft.	0.28	.....
Electric fuses, 389:		
8 ft. long, 49	2.13	.....
10 ft. long, 19	0.92	.....
12 ft. long, 257	13.67	0.005
14 ft. long, 64	3.71	.....

Material, Rental, Interest and Depreciation (Cont'd): Ledge Rock:	Cost.	Cost per ton on output.
Cotton fuse, 3,522 ft.	10.15	.....
Percussion caps, 1,183	8.88	.....
Stone dust for tamping holes, 3 tons	3.00	.....
Cylinder oil, 20 gals.	6.32	.....
Machine oil, 40 gals.	0.64	0.001
Waste, 22 lbs.	1.65	.....
Steaming coal, 30 tons	126.11	0.014
Rental of small tools (at $0.05 per man per day) 1,815 man days (excluding blacksmith and helper) at $0.05	90.75	0.010
Rental and repairs of steam drills (including piping, hose, etc.), 153 drill days, at $0.50	76.50	0.008
Buildings	38.51	0.004
Crusher:		
Steaming coal, 30 tons	126.10	0.014
Cylinder oil, 14½ gals.	5.28	.....
Machine oil, 126 gals.	22.17	0.003
Waste, 51 lbs.	3.81	.....
Sal soda, 48 lbs.	0.36	.....
Rosin, 1 lb.	0.04	0.001
Belt lacing, 300 ft.	4.50	.....
Sheet steel (11½ ins. by 1¼ ins.), 14 ft.	6.00	0.001
Crusher plates (two new, over half worn), at $211.80, less 50%	105.90	0.012
Rubber belting installed (new), $89.12, less 90%	8.91	0.001
Rental on small tools (at $0.05 per man per day), 250 man days (exclusive engineer, fireman, oiler and weigher), at $0.05	12.50	0.001
Interest and depreciation on plant, three mos., at $149.25	447.75	0.050
Adjusting scales	4.76	0.001
Total material, rental, etc.	$1,550.51	$0.174
Labor and teaming	7,907.65	0.882
*Total charged to output	$9,458.16	$1.056
Permanent repairs: Repairs to scales	68.44	0.008
Total cost of test	$9,526.60	

*Does not include estimated cost of stripping done prior to beginning of test, amounting to $223.83, and does not include cost of quarrying 200 tons of stone remaining unbroken at end of test, amounting to $50.

The report states that large stone contractors in the vicinity of Boston sell stone f. o. b. cars at about one-half the above given cost with city forces. Yet this test was made with the full understanding that it was to be a crucial test of the city forces.

Data on Jaw Crushers.—The size of jaw crushers is commonly denoted by the size of opening through which the stone passes to the jaws. A 9 x 15-in. crusher is one having an opening 9 ins. wide by 15 ins. long; which is the common size for portable plants. To move such a crusher a few miles from one location to another, set up the bins, etc., preparatory to crushing, costs about $75, according to the author's experience. The main part of this cost consists in tearing down and rebuilding the bins, mounting the rotary screen and adjusting the bucket elevator. There are several makes of portable bins on wheels now in the market, and with

these the cost of moving should be much reduced. A large bin capacity, however, is desirable to "tide over" any irregularities in the hauling and in the operation of the crusher itself. Bins should always be used to save the cost of shoveling the broken stone into wagons.

Data on Gyratory Crusher.—The gyratory crusher is now largely used on large permanent plants. The following are the sizes of the style "D" Gates gyratory crusher:

Size. No.	Diameter at top out to out.	Size of each receiving opening.	Weight of crusher, lbs.	Tons per hr. to 2½-in. size.	HP. for crusher, elevator and screen.
1	3 ft. 6 ins.	5 × 18 ins.	5,500	4 to 8	8 to 10
2	3 ft. 10 ins.	6 × 21 ins.	8,000	6 to 12	12 to 15
3	4 ft. 6 ins.	7 × 22 ins.	14,000	10 to 20	20 to 25
4	6 ft. 8 ins.	8 × 27 ins.	21,000	15 to 30	25 to 30
5	7 ft. 10 ins.	10 × 30 ins.	30,000	25 to 40	30 to 40
6	8 ft. 7 ins.	11 × 36 ins.	42,000	30 to 60	40 to 60
7½	10 ft. 8 ins.	14 × 45 ins.	63,000	75 to 125	75 to 125
8	11 ft.	18 × 63 ins.	94,000	125 to 200	100 to 150

The output is given in tons of 2,000 lbs. per hour of rock crushed to pass a 2½-in ring.

In the section on Concrete will be found the cost of crushing with a No. 7 Gates crusher for a retaining wall on the Chicago Canal. The first cost of the crusher was $12,000. Its output averaged 210 cu. yds. per 10 hr. day. The crusher was capable of a much greater output, for we have already recorded a 200 cu. yd. daily output with a No. 5 Gates (see page —), which is itself not a big record.

In large crushing plants the general practice is to have one large gyratory crusher that receives the big chunks of rock, and a smaller gyratory, or a jaw, crusher that re-crushes all that does not pass through a 2½ or 3 in. screen.

The following data of output were published in *Engineering-Contracting*, July 21, 1909, and relate to limestone.

The Lake Shore Stone Co., Belgium, Wis., have a plant consisting of a No. 9 Gates crusher and a No. 6 Austin, and their average output of all sizes of stone up to 2½ ins. is 600 cu. yds. per 10 hrs., with a maximum output of 750 cu. yds. The stone is fed to the crusher from a hopper by one man. Stone is delivered to the hopper by cars, 44 men being engaged in loading these cars. The stone is a very hard dolomitic limestone.

The Elk Cement & Lime Co., Petoskey, Mich., have a plant of one No. 5 Austin and a No. 3 Gates. They break 450 tons per 10 hr. day, the maximum output being 500 cu. yds. Two men feed the crusher. No crushed stone is larger than 2½ ins., hard limestone.

Holmes and Kunneke, Columbus, O., run a No. 3 Austin. The output is 80 to 120 cu. yds. per 10 hr. day, no stone being over 2 ins. in size. Two men feed the crusher. The rock is hard limestone.

A No. 8 Gates gyratory crusher having a hopper 11 ft. in diameter, operating at a speed of 140 gyrations per minute, and having a total weight of 45 tons, was installed in 1896 at the quarries of the

Pittsburg Limestone Co., Newcastle, Pa. Mr. Geo. W. Johnson, president of the company, states that in 14 mos. the output was 556,000 long tons of limestone crushed for blast furnaces. The best month's work was 47,472 tons in August, 1896, the average of the 14 mos. being slightly less than 40,000 tons per month. During the 14 mos. only 14 days were lost. The best day's work was 2,250 long tons in 10 hrs. I have been unable to secure a statement as to the size of the broken stone, but stone crushed for a blast furnace is larger than for macadam, ballast or concrete, usually being about 6 ins. diameter.

Cost of Breaking Stone by Hand.—I have found that in breaking limestone, a good 10 hrs. work for a skilled man is 3 cu. yds. broken to 2-in. sizes, but 2 cu. yds. are all that an inexperienced man can break.

Aitken states that in England a good hand-breaker can produce 3 to 4 cu. yds. of ordinary macadam per day "out of such material as flints, the harder limestones, field stones and river gravel." He says that 2 to 2½ cu. yds. of brittle whinstone, or ¾ to 1½ cu. yds. of basalt, granite and the tougher kinds of whinstone, constitute a good day's work.

In *Engineering-Contracting*, Sept. 15, 1909, the results are given of a test (in England) with different kinds of hammers used to break quartzite. It was found that chisel hammers produced 28% less fines (under 1½ in. size) than round hammers, the percentage of fines with the chisel hammers being only 5¼% of the total of 500 tons broken, as compared with 7⅓% with round hammers.

Diamond Drilling.—For determining the nature of bridge foundations, the character of proposed canal or railway excavations and for prospecting for mineral deposits, the diamond drill is an invaluable machine. The bit of a diamond drill consists of a number of diamonds mounted on the end of a hollow tube. This bit is rotated by hand, steam, air or electric power, while at the same time water is pumped down the hollow drill rods and passes up outside of the rods, carrying away the rock dust made by the grinding of the diamonds against the rock. The bit cuts an annular channel, leaving a core of rock inside the core barrel. When the drill has penetrated the rock a distance of 6 to 10 ft., the drill rods are raised and the act of raising them breaks off the rock core, which is brought to the surface in the core barrel and kept for examination.

The diamonds are preferably black diamonds, known in the trade as "carbons"; but where the rock is soft, white diamonds, known as "bortz," may be used. Sometimes both kinds are used in one bit. A bit usually has 6 to 8 carbons weighing 1 to 1½ carats each. Small stones are not economical because after a carbon has been worn down so that it weighs less than about ½ carat it cannot be reset. In selecting carbons reject those showing a cokey structure, also those having thin, sharp edges. Carbons having straight edges with sides forming an obtuse angle of 95° to 140° are most durable. The cleavage should be tested with a pair of hand pincers. Old stones that have been used are to be preferred since a poor

stone will break in use, and no test is so satisfactory as the test of usage. The carbons selected for a bit should be quite uniform in size.

When diamond drilling was first introduced into this country it was predicted that it would be used exclusively for drilling blast holes, and in fact diamond drills were used on the Sutro tunnel for a while, and in sinking one or two shafts by the "long hole" method, which involved drilling holes several hundred feet deep, filling them with sand, then removing the sand for about 8 ft., charging with powder, firing, and so on. The development of machine drills using steel bits and the steady rise in price of carbons have together shown these early predictions to have been fathered by hope rather than by reason.

The following cost data on diamond drilling have been abstracted from my book on "Rock Excavation":

The sizes of holes and cores are as follows:

Hole, diam. in ins...........	1⅝	1¾	2	2⅝	3 9/16
Core, diam. in ins...........	15/16	1 3/16	1 7/16	2	2⅞

Price of Diamonds.—In 1873 the price of carbons per carat was $8 to $12. I am indebted to the Standard Diamond Drill Co., of Chicago, and to the Yawger-Lexow Co., of New York, for the following statements as to the average cost of carbons per carat from 1895 to 1903:

1895.	1896.	1897.	1898.	1899.	1900.	1901.	1902.
......	$36	$50	$60	$55	$50	$45	$50
$18.50	$28	$35.50	$35.50	$36	$51.50	$48.50	$47

It will be noted that these firms do not agree very closely as to prices prior to the year 1900. The American Diamond Rock Drill Co., of New York, quoted $52 per carat for best selected carbons and $16 per carat for best selected borts in November, 1902.

There is no import duty on carbons in the United States, Canada or Mexico.

Water Required.—In boring a 2-in. hole where the progress is about 10 ft. per 10-hr. shift, from 100 to 125 gals. of water are required to wash out the sludge formed in drilling, provided the water is used but once. In cases where the water is expensive it is customary to collect the return water in a settling tank and use it over and over; and, unless a large amount of water escapes through crevices, 30 or 40 gals. per shift will be consumed by evaporation and leakage.

Price of Diamond Drills.—A hand power drill that can be used to bore a 1⅝-in. hole (giving a 15-16-in. core) up to a depth of 350 ft.; or a 2⅝-in. hole (giving a 2-in. core) up to a depth of 250 ft., will cost approximately $850 f. o. b. New York or Chicago. This includes 300 ft. of pipe, 6 carats of carbons, all tools, etc., necessary. The machine alone weighs 330 lbs., and can be divided into packages weighing 40 lbs.; but the whole outfit packed for shipment weighs 2,800 lbs. If it is desired to run this drill by horse power, $60 additional will purchase the horse power equipment. A hand power plant capable of drilling 50 per cent deeper than the above costs about $1,400.

A steam power plant that can be used to bore a 1⅝-in. hole 800 ft. deep, or a 2⅝-in. hole (2-in. core) 500 ft. deep, costs about $2,400, including the 8 hp. boiler on wheels; the drill itself costing $1,100, the boiler $400; 1 set of carbons (9 carats), $450, and the balance for sundries. The drill itself weighs 600 lbs., but the full outfit packed for shipping weighs 10,000 lbs.

A steam power plant that can be used to bore a 1¾-in. hole 1,500 feet, or a 2⅝-in. hole 1,000 feet, can be purchased for $4,600; of which $2,400 is for the drill, $500 for the 15 hp. boiler on wheels, $600 for 12 carats of carbons and the balance for rods and sundries. This outfit weighs 20,000 lbs.

Cost of Diamond Drilling in Virginia.—There is a great deal to be found in print relative to the cost of diamond drilling, but unfortunately the records as published are in such form as to be of far less value than they should be. By this I mean that any record of any kind of drilling to be of great value should give: (1) The rate of penetrating a given kind of rock when the drill is actually cutting; (2) the speed, power and weight of the machine; (3) the time lost in raising the drill to change bits, remove cores, or the like; (4) the time required to shift from one hole to the next; (5) the average time lost in repairs, breakdowns, etc.; (6) the diameter and depth of hole; (7) the time consumed in driving and pulling casing. No record in print contains all these factors. Strangely enough, one of the earliest printed accounts contains more of these factors than any subsequent record. I refer to an admirable paper by O. J. Heinrich, in *Trans. Am. Inst. Min., Eng.,* 1874, from which I have abstracted the following:

The diamond drill crew consisted of three men, two to run the drill and one to help raise the drill rods, beside a foreman. The shift was 12 hrs. long, and the following was the cost of operating a shift:

Foreman, or boring master	$2.50
Mechanic, or engineer	2.00
Assistant	1.50
Laborer	1.00
Total labor	$7.00

The coal consumed was 10 lbs. per hp. per hr. For holes up to 1,000 ft. deep an 8-hp. engine was used, the drill rods weighing 4,500 lbs.; but up to a 1,500-ft. hole a 12 hp. engine was used, with rods weighing 7,000 lbs. The drill had a 2-in. bit, on which were mounted never less than 12 carbons, better 16. The drill rods were raised after every 1¼ ft. of drilling. The drilling was done in Chesterfield county, Va., prospecting for coal, in 1873. The cost of operating per shift is given as follows:

Labor	$ 6.50
⅓ ton coal at $3	1.00
Oil	0.50
Diamonds and repairs	11.00
Interest and depreciation	1.92
Total per day	$20.92

The price of carbons was $10 per kt. Rates of wages were also much lower then, and it should be noted that the allowance for interest and depreciation is too low for a plant costing $7,200, as it is stated this 8 hp. plant cost.

Depth of hole in earth and rock	419	850	1,142
Depth bored in rock	396	826	1,118
No. of 12-hr. shifts actually boring	13.88	44.41	59.29
No. of 12-hr. shifts raising rods	15.87	59.34	116.46
No. of 12-hr. shifts incidentals	3.25	15.25	68.25
No. of 12-hr. shifts total	33.00	119.00	224.00
Ft. progress per hr. while boring	2.37	1.55	1.57*
Ft. progress per hr., average	0.998	0.578	0.308
Cost of labor, per ft.	$0.36	$0.59	$1.02
Cost of fuel ($3 ton) per ft.	$0.53	$0.14	$0.17
Cost of all other items, incl. materials and blacksmithing	$1.29	$1.43	$2.05
Interest	$0.16	$0.27	$0.38
Total cost per ft.	$1.86	$2.43	$3.62

From the data given by Mr. Heinrich I have prepared the following formulas to be used in computing the number of hours required to drill a hole of given depth.

Let

T = Total number of minutes required to bore the hole.

n = total depth of hole in feet.

l = length of each coupling rod = 10 ft. in this case.

t = the number of minutes required to bore 1 ft. of the hole. In the formation given by Heinrich $t = 19$ mins. per ft. of hole up to a depth of 300 ft., to which add 5 mins. per ft. for each 100 ft. of increased depth.

r = time in minutes required to raise and lower the rods including 2 mins. to uncouple and couple up.

$r = 7$ mins. for hole up to 300 ft plus ½ min. for each additional 100 ft.

s = number of lengths of coupling rod.

The time consumed in actual boring in feet is obviously nt. The time consumed in raising and lowering the drill rods is the sum of an arithmetical series in which s = the number of terms and r = the common difference; hence the sum is $\frac{1}{2}s\ (2r + [s-1])r$, which reduces to $\frac{s(1+s)r}{2}$. The total time is therefore:

$$T = nt + s\frac{(1+s)}{2}r$$

$$s = \frac{n}{l}$$

$$T = nt + \frac{n\ (l+n)}{2\ l^2}r$$

If $l = 10$

$$T = nt + \frac{n\ (10+n)}{200}r$$

$$T = nt + \frac{n^2\ r}{200}, \text{ nearly.}$$

For holes of the following depths we have

	Ft.	Ft.	Ft.
n =	400	800	1,200
t (minutes) =	24	44	64
r (minutes) =	7 1/3	8 2/3	10
T (minutes) =	14,300	63,000	148,800
T (hours) =	240	1,050	2,480

On Heinrich's work about 10% more time than the above was required to cover losses from delays arising from various causes. The point that is strikingly brought out by Heinrich's records is the rapid falling off in the rate of speed of drilling each foot of hole with increased depth. The cause is obvious, however, for the longer the line of drill rods the greater the friction of the rods upon the sides of the drill hole, and consequently the slower their revolution with an engine of limited horse power. The increased weight of the rods with increased depth also reduced the rate of speed with which they are hoisted by the engine; and this is a very important factor in adding to the labor and fuel cost of drilling deep holes. Heinrich's estimates of the time required to drill holes, including all 10% allowances for delays, are as follows:

400-ft. hole	288 hours
800-ft. hole	960 hours
1,200-ft. hole	2,616 hours

It will be observed that these times check fairly well with the times obtained by applying the formula that I have given; but it should be added that the constants in the formula need further verification by other observers. The material penetrated in the 800-ft. hole was:

Hard silicious sandstone	210 ft.
Medium silicious sandstone	262 ft.
Argillaceous sandstone and slate	237 ft.
Limestone	18 ft.
Total	827 ft.

Heinrich's estimates of time, and my own formula based thereon, assume a uniform sandstone throughout in the three holes. Had the rock been uniform throughout, the cost would have been:

400-ft. hole, at $1.26	$ 504
800-ft. hole, at 2.10	1,680
1,200-ft. hole, at 4.00	4,800

Cost of Diamond Drilling in Lehigh Valley.—Mr. L. A. Riley is authority for the following work done in 1876: Two machines belonging to the Lehigh Valley Coal Co. were used. A No. 2 drill with 16 hp. boiler and 1,000 ft. of 2-in. rod cost $3,000, which with diamonds, etc., came to $5,000; the weight being 3,500 lbs. Carbons cost $9 per carat, and borts cost $11. Five diamonds weighing 18 carats were used per bit, drilling a 2-in. hole and bringing up a 1½-in. core. There were 24 holes, aggregating 9,902 ft., the deepest being 900 ft. The average rate of drilling these holes was 19 ft. per day per machine, at an average cost of $2.22 per ft. The rock was a very hard sandstone and conglomerate. The force on each drill was one foreman, one engineer and one fireman. The average cost per ft. of hole was:

Labor	$1.15
Diamonds	.66
Supplies and repairs	.41
Total	$2.22

The cost of the 900-ft. hole (the deepest) was $1.95 per ft., which indicates that with a powerful (16 hp.) engine there is no such great increase in cost per ft. with increased depth as Heinrich found with an 8 hp. engine. The 16-hp. plant used by Riley was capable of drilling a 2,000-ft. hole. Note especially that both Riley and Heinrich paid less than $10 a carat for carbons and that Riley does not say what proportion of carbons to borts were used.

Cost of Diamond Drilling on Croton Aqueduct.—Mr. J. P. Carson, gives the following:

Fourteen holes, total, 2,084 ft., were drilled in the year 1895.

Actual days worked	189 days
Moving drill	15 days
Idle	18 days
Holidays and Sundays	39 days
Total	261 days

	Daily progress. Feet.	Cost per ft.
347 ft. hard gneiss	11 to 12	$3.97
814 ft. decomposed gneiss	23.1 to 28	1.15
572 ft. clay, gravel and boulders	6.7 to 9	4.07
351 ft. clay and gravel	25	.....
2,084 ft. Average	10.2	$2.91

Crew, 1 foreman at $125 mo.; 1 assistant foreman at $70; 4 men at $65.

Wages, 8.1 mos.	$3,785
Team moving	80
66.7 tons coal (189 days)	360
Supplies, Diamond Drill Co.	472
Foundry	291
Lumber, rope, etc.	53
Interest on $6,000 plant at 12% 8.1 mos.	486
Renewing diamonds	250
Diamond bit lost	300
Total, 204 days	$6,077
Average per day	$29.79
Average per ft.	$ 2.91

Note that the item of interest is evidently intended to include depreciation, but, if so, it is altogether too low.

Cost of Hand Diamond Drilling in Arizona.—Mr. J. B. Lippincott gives the following data on diamond drilling at the Gila River Dam site, Arizona, in 1899. The machinery was in two distinct parts, (1) the hand pile driver for sinking casing pipe to bed rock; (2) the diamond drill. The hammer, made by the Pierce Well Co., 120 Liberty street, New York, is in sections, so that its weight can be varied up to 190 pounds; it is raised by a hand winch, and tripped by nippers; maximum drop 11½ ft. A tool-steel head is screwed into the top of the pipe and receives the blow. The pipe is 3½, 2½ and 2 in., extra heavy, screw pipe, 5 ft. sections, with extra heavy couplings, which have beveled edges. When the casing has reached bed rock, the sand inside is removed by using a chopping

bit and a water jet. The bit is screwed to a ¾-in. pipe through which water is pumped by a hand pump, the water passing out through holes in the bit, thus bringing the sand to the top of the casing. In this manner a casing pipe 130 ft. deep can be cleaned of sand and gravel. If a boulder is struck, after the diamond drill has penetrated it, four or five sticks of dynamite are lowered and discharged, shattering the boulder so that the casing can be driven down.

The diamond drill was made by the American Diamond Rock Drill Co., New York City. One inch core bits were usually employed. The drill was operated by hand power, six men being employed on this work as well as on driving the casing. The drill will penetrate 200 ft. into rock, and will make 6 to 8 ft. per day in hard rock and 10 to 15 ft. per day in soft rock. The plant complete costs $1,000, including two diamond bits worth $200 each, set with six 1-carat diamonds each. Two machines were used. The pipe cost $600 and freight, $100.

Cost of operation per month, foreman	$150	
6 laborers at $1.50 for 28 days	234	
1 cook	45	
		$ 429
240 rations at 60 cts.		144
Total labor for one month		$573
Total repairs, pipe and lumber for one party for 10 months		$ 500
Team, feed, etc.		350
Moving		670
Sundry incidentals		430
Supervision		350
Total supplies, etc., for 10 mos.		$2,300
Total labor, 10 mos.		5,730
Total		$8,030
Total number of feet sunk		3,254
Cost per ft.		$ 2.46
52 holes, cost per hole		$154.42

Total Depths Penetrated.

	Earth, ft.	Rock, ft.	Total, ft.
The Buttes	1,621.2	196.0	1,817.2
Queen Creek	357.8	55.6	413.4
Riverside	729.8	40.2	770.0
Dykes	80.0	0.0	80.0
San Carlos	143.2	30.4	173.6
	2,932.0	322.2	3,254.2

A month's time of one party was lost due to continual breaking of the casing pipe under the hammer. Note that 90% of the drilling did not involve the use of diamonds but consisted in driving through the earth covering overlying the rock. This is characteristic, however, of testing dam sites.

Cost of Diamond Drilling in Pennsylvania.*—Mr. E. E. White is author of the following:

***Engineering-Contracting*, Apr. 21, 1909, reprinted from "Engineering and Mining Journal."

The following notes on progress and cost of drilling in the coal measures of Greene county, Pa., were taken from April 20, to July 13, 1908. I was on the ground practically all of the time, representing the company who had optioned the coal, and so had a chance to obtain correct figures on the progress of drilling. The costs are not as accurate, but are essentially correct.

The cost of superintendence and carbons is estimated. The superintendent, C. C. Hoover, of the Birdsboro Steel Foundry & Machine Co., which concern took the contract for drilling, was on the ground only one day. As he was looking after about half a dozen other drills, the estimated cost for superintendence is liberal. The cost for carbons would have been much less but for the fact that 2¼ carats were broken at a depth of 21 ft. in the first hole, probably by a piece of steel in the hole. This bore was abandoned and another started 2 ft. away.

The drill only worked a day shift, and was run by two men, the drillman, H. N. Wighaman, and a fireman. Bits were set in the company's shop, not in the field. The hours in the progress table refer to the drill, that is, to two men, except in the case of hours setting bits.

The drill had a hydraulic feed and a double-core barrel, taking a 2½-in. core. The outfit, with one good diamond bit, is furnished by the Birdsboro Steel Foundry & Machine Co., of Birdsboro, Pa., for about $3,500.

Considerable trouble was experienced with the boiler on the first two holes, which was accountable for a large part of the hours' delay on these holes, shown by the progress table. The boiler was of the upright type, set behind the machine on the heavy wagon frame. There were no stay bolts, and the flues frequently had to be rolled every three or four days after the first week, and finally were rolled every day for three days in succession. After stay bolts were put in, the flues were not rolled again on the job. Except for the boiler and a troublesome donkey pump which supplied the water tank, the outfit was excellent. The delay on the last hole was mostly waiting for water, which had to be pumped a little over a quarter of a mile.

The expense of pumping on the last hole is not included, as it was borne by the owners of the coal. The contract read that water should be furnished within 100 ft. of each hole. The cost of moving on and off the ground is not included, as it would be variable, according to the distance and means of transportation. The distance moved between holes averaged about a mile by road. It was open country with good roads, so that moving was not expensive.

The core obtained was practically complete, both of rock and coal. The surface was from 6 to 19 ft. deep, averaging 9 ft. 9 ins. It was clay, with no boulders, and was drilled out with a mud bit.

The table showing rates of drilling in different kinds of rock is the average of many observations on the five holes. The rate is,

of course, dependent largely upon the drillman and how much pressure he cares to put upon the bit.

Both cost and progress tables are from the time the drill reached the ground until ready to leave:

BITS USED.

	Distance Drilled.	Estimated Carbon Wear.
Mud-bit	48 ft. 7 in.	
Diamond bit No. 1 (carbons broken by steel?)		2¼ carats
Diamond bit No. 2 (hole No. 1)	369 ft. 8 in.	½ carat
Diamond bit No. 3 (hole No. 2)	339 ft. 0 in.	½ carat
Diamond bit No. 4 (holes Nos. 3, 4)	500 ft. 1 in.	½ carat
Diamond bit No. 5 (hole No. 5)	562 ft. 8 in.	½ carat
	1,820 ft. 0 in.	4¼ carats

RATE OF BORING.

Kind of Rock.	Ft. per Hour Actual Cutting.
Shale	7.05
Fire clay	7.10
Limestone	7.20
Sandstone	9.35
Coal	15.15

COST TABLE.

	Cost.	Cost per ft.
Drillman	$ 307.70	$0.169
Fireman	192.31	0.106
Blank bits	5.00	0.003
Setting bits	10.00	0.005
Carbons (4¼ carats, at $90)	382.50	0.210
Fuel (1,050 bus. coal)	67.17	0.037
Oil and waste	11.00	0.006
Repairs	24.85	0.014
Moving	36.00	0.020
Superintendence	200.00	0.110
Total working cost	$1,236.53	$0.680
Depreciation of outfit (20% on $2,000 for 3 mos.*)	100.00	0.055
Total costs exclusive of freight and hauling on drill and wages and expenses of drillmen to and from Greene county	$1,336.53	$0.735

*The outfit exclusive of the bit is worth about $2,000.

Table XI shows the time and progress of drilling.

Mr. Hoover, of the Birdsboro Steel Foundry & Machine Co., makes the total cost $1.18 per foot, but I think that figure must be rather high. Four holes put down by the same company in Raleigh county, West Virginia, are said to have cost $2.90 per foot.

Consumption of Diamonds in Diamond Drilling, Tennessee.—The cost of carbons and borts consumed in boring 39 underground holes at the Burra Burra and London mines, Ducktown, Tenn., is shown in Table XII. The holes were drilled in 1907 with two Sullivan machines of the "S" type, and all but three holes, aggregating 284 ft.,

TABLE XI.—PROGRESS OF DRILLING.

	Hole No. 1.	Hole No. 2.	Hole No. 3.	Hole No. 4.	Hole No. 5.	Totals and Averages.
Feet drilled	377.5	358.0	279.4	236.4	568.7	1,820.0
Hours actual cutting	54.44	40.00	35.07	27.45	75.90	232.86
Hours pulling core, lowering rods, etc.	38.81	31.00	23.43	18.30	60.85	172.39
Hours drilling	93.25	71.00	58.50	45.75	136.75	405.25
Hours delay, steaming, repairs	66.50	62.25	11.75	18.75	63.00	222.25
Hours tearing down, moving, setting up	20.00	30.00	25.00	20.00	46.75	141.75
Total hours	179.75	163.25	95.25	84.50	246.50	769.25
Hours setting bits	8	4	4	0	4	20
Feet per 10-hr. shift after setting up*	23.60	31.58†	39.83	40.83	28.50	29.97†
Feet per drilling hour*	4.05	5.05	4.75	5.15	4.15	4.49
Feet per hour actual cutting*	6.94	8.95	7.95	8.62	7.50	7.82

*Excludes hours setting bits.

†Excludes 20 hours putting stay bolts in boiler.

TABLE XII.—ANALYSIS OF STONE CONSUMPTION.

Feet Drilled. Total.	Vein.	Country.	Stones Consumed.	Cost per Carat.	Total Cost.	Consumed per Foot.	Cost per Foot.
1,437	411	1,026	25 55/64k.	Borts at $10..............	$258.60	$\frac{1.151}{64}$k.	$0.18
546	65	481	16 17/64k.	Borts, 7 13/64 at $10........ Borts, 9 4/64 at $15........	72.03 135.94	$\frac{1.304}{64}$k.	0.3809
798	226	572	14 45/64k.	Borts at $15	220.55	$\frac{1.179}{64}$k.	0.2764
167	90	77	8 30/64k.	Borts, 6 42/64 at $15....... Carbons, 1 52/64 at $85....	99.84 154.06	$\frac{3.246}{64}$k.	0.9225
840	228	612	5 2/64k.	Carbons at $85............	427.66	$\frac{0.383}{64}$k.	0.5090
3,788	1,020	2,768	70 4/64k.	Totals and averages.......	$1,368.68	$\frac{1.184}{64}$k.	$0.3613

were horizontal across the formation. The core was 15/16 in. diameter and the holes 1½ ins. in diameter.

The highest cost per foot was $3.66, in a horizontal hole started in the footwall and drilled to a depth of only 8 ft., consuming 1.61/64 k. of $15 borts. Excepting this hole, which penetrated very hard blue quartz, the highest cost for a hole drilled with borts was $0.8338 per ft. This hole was drilled in the footwall of the Burra Burra mine to a depth of 52 ft., 37 ft. being in hard silicious vein material and 15 ft. in country rock; 2.57/64 k. of $15 borts were consumed in boring it.

The lowest cost per foot was $0.0321, and was obtained from a horizontal hole bored to a depth of 190 ft. in the hanging wall of the Burra Burra mine. This hole penetrated 10 ft. of vein material at its mouth, and the remainder cut through soft mica schist so thinly foliated that there were but few pieces of core recovered more than ½ in. thick. The stone consumption was only 39/64 k. of $10 borts.

Cost Using Carbons.—The highest cost of a hole drilled with carbons was $1.155 per ft. This hole was drilled in the footwall of the London mine to a depth of 92 ft. and penetrated 22 ft. of vein and 70 ft. of country rock. The loss in stones was 1¼ k. at $85. The lowest cost with carbons was $0.0718 per ft., from a hole in the footwall of the London mine which penetrated 80 ft. of vein and 44 ft. of country rock. The stone consumption for the hole was 1/16 k., at $85.

Cost Using Borts.—The stone consumption given in the tables does not take into account the loss from scrap borts in the drilling. This loss was: 4.58/64 k. at $15, $73.59; 5.57/64 k. at $10, $58.90; total, 10.51/64 k., $132.49. The above amount distributed to the 2,948 ft. drilled wholly and in part with borts gives an additional cost of about 4½ cts. per ft. for holes drilled with these stones. There was no loss in carbon scrap, this loss occurring usually when the stones have worn too small to be utilized in a bit.

Summarizing and leaving out of the calculations those holes where both borts and carbons were used, the costs with borts were for 2,781 ft. drilled, $687.12, or the cost per foot, $0.247. The additional loss for scrap, which amounted to $0.045 per ft., brings the cost up to $0.292 per ft. This is considerably less than the carbon cost of $0.5090, given in the table.

Adaptability of Each Stone.—Borts may be profitably used in drilling soft ground, but in hard material they are useless, as the stones, all of which contain flaws, will shatter when encountering hard rock. It is doubtful if borts could have been used with cheaper results in drilling the 840 ft. that were drilled with carbons. Some of this ground they would not have cut without great waste. Where part carbon and part borts were used, the carbons were substituted for the borts when it was found that the borts would not stand the work.

In some formations, where there are strata or zones of varying degrees of hardness, bits set with carbons might alternately be

used with those set with borts, but the bits could not very well be set in advance owing to the varying gage of the hole.

Cost of Diamond Drilling in British Columbia.*—Mr. Frederick Keffer is author of the following:

Two years ago I contributed to the Institute a paper on the results of diamond drilling as carried on at the mines of the British Columbia Copper Company, Limited during 1905. That paper gave some details as to costs, and the period covered was but 8½ months. Since that year drilling has been carried on more or less continuously in the mines of the company, and the results of this work, so far as progress and costs are concerned, are given in detail in the following tables.

Table XIII gives the monthly results of work as well as the yearly totals. It is, of course, important to know the general character of the rock drilled in order to institute comparisons with other localities. In the narrow limits of this table it is not possible to give details as to rocks, but as nearly as possible the rocks comprise diorites, compact garnetites and certain very hard and silicious eruptives occurring in Summit camp. The medium hard rocks include all ores, and, in Deadwood camp, much of the greenstone country. The soft rocks are the limestones porphyries and serpentines. Of all rocks drilled the garnetites proved much the most severe in diamond consumption, as is illustrated by the work from May to August, 1907, which was mainly conducted in garnetite with some silicious limestones.

Eight hours constitute a shift underground, and nine hours on the surface. On Sundays no work is done apart from repairs to machinery. In May, 1906, the labor was contracted as an experiment, but was abandoned as being unsatisfactory.

The employes were, normally, a runner and a setter. Extra help was required at times for blasting places for good set ups, for laying pipe lines, moving plant, etc. In August, 1907, two shifts were employed. In June and July of that year the increase in labor costs is mainly on account of the long pipe lines required.

The power consumed is taken as being equivalent to that required for a 3¼-in. machine drill, that is to say, about 20 hp. When drilling at a mine, where for example 15 machines are used on each shift, the diamond drill is charged with 1/31 of the total power costs—it being in this instance run on one shift only.

Where steam power is used either directly or through a steam driven air compressor, the costs are much increased. Where, as in some cases, an isolated 24-hp. boiler was used, the power costs are still higher, as an engineer has to be provided as well as a team to haul wood.

Tools, repairs, etc., include these items as well as all small miscellaneous expenses. The increasing cost of diamonds ($80 per

**Engineering-Contracting*, May 6, 1908; abstract of a paper before the Canadian Mining Institute, with additional data furnished by the author.

TABLE XIII.—PROGRESS TABLE.

Date.	Depth of holes. Total feet.	Hours actual drilling.	Hours moving to new holes, setting bits, etc.	Total hours.	No. of holes.	Carats used.	Ft. per drilling hour.	Character of Rock.
Jan., 1906	170	106	46	152	6	61-64	1.60	Mainly hard diabase.[1]
Feb., 1906	191	104	24	128	3	3 47-64	1.83	Softer lime rock.[3]
March, 1906	398	205	77	282	5	3 35-64	1.94	Equal parts of above rocks.[2]
April, 1906	214	76	55	131	7	1 59-64	2.81	Lime rocks and ore.[3]
*May, 1906	463	...	..	...	4	5 36-64	....	Nearly all in ore.[3]
August, 1906 ...	508	160	48	208	7	3 25-64	3.17	Fairly hard rock.[2]
Sept., 1906	96	29	3	32	0	46-64	.31	Mainly ore.[3]
Oct., 1906	235	95	53	148	4	2 19-64	2.45	Mainly ore.[3]
Nov., 1906	411	157	63	220	6	2 40-64	2.62	Hard silicious rock.[1]
Dec., 1906	316	144	48	192	3	4 8-64	2.19	Hard silicious rock.[1]
Total	3,002[7]	1,076	417	1,493	45	28 56-64	.359[4]	
Jan., 1907	411	159	57	216	6	1 3-64	2.58	Limes and porphyry.[3]
Feb., 1907	378	137	79[5]	216	2	1 50-64	2.76	Ore and limy rock.[3]
March, 1907	540	180	28	208	5	2 37-64	3.00	Ore and limy rock.[3]
April, 1907	464	181	27	208	1	3 18-64	2.56	Ore and limy rock.[3]
May, 1907	500	163	53	216	3	5 4-64	3.07	Hard garnetite.[1]
June, 1907	477	187	39	226	6	5 16-64	2.55	Very hard garnetite.[1]
July, 1907	400	203	23	226	6	7 3-64	1.97	Very hard garnetite and diorites.[1]
Aug., 1907.......	497	213	129[6]	342	8	4 44-64	2.33	Very hard garnetite.[1]
Total	3,667[8]	1,423	435	1,858	37	30 47-64	2.577	

*This month's work was contracted as to the labor. Feet drilled are therefore not included in averages as contractor worked overtime.

[1] Hard rocks. [2] Medium hard rocks. [3] Soft rocks.

[4] Averages calculated on 3,002 ft. less 463 drilled on contract.

[5] Several days lost moving 15 miles to another mine.

[6] Much trouble with caving ground in August. Worked two shifts nearly all the month.

[7] Of these 3,002 ft., there were 1,523 ft. vertical and 1,479 ft. horizontal.

[8] Of these 3,667 ft., there were 1,573 ft. vertical and 2,004 ft. horizontal.

carat in 1907 as compared with $60 in 1906) added materially to cost per foot in 1907.

The carats used per foot were 0.572/64, or in more intelligible decimals, .00893 carats, so that one carat on the average drilled 111.9 ft. All holes over 30 degrees dip are classed as vertical, and ft. per hr. in horizontal holes is about 15% greater than in vertical ones. The average depth of holes is 81.3 ft., and diameter of cores is 15/16 ins.

In comparing these costs with contractors' prices, it must be borne in mind that contractors usually require air (or steam) and water to be piped to the work, and the mine must in addition furnish the air and water free of charge. In the present cost sheets all these items are charged against costs of drilling.

The drill runner set and was responsible for the diamonds. He was paid a salary of $175 per month, while two helpers, during the period of time given, received $3.50 per day. Since the decline in the price of copper, helpers are only paid $3.30 per shift. The compressor men receive $4 per day.

Wood for fuel costs $3.50 to $5 per cord, according to locality. Electric power costs $33 to $40 per hp. per year.

The drilling was done with a "Beauty Drill," of the Bullock type, made by the Sullivan Mchy. Co., of Chicago. The machine has been in service three years and is in excellent condition. The catalog price of the drill is $1,500, with its equipment, including 2 bits ready for carbons, but not including carbons. The shipping weight is 1,160 lbs. It will drill to a depth of 800 ft., making a hole 1 9/16 ins. diam. and giving 15/16 in. core.

The following were the unit costs in 1906 and in 1907, also in March, 1907, when the lowest unit cost was secured:

Cost in 1906 (3,002 Ft. Drilled).

	Per lin. ft.
Labor	$0.786
Power	0.205
Repairs, oil, etc.	0.109
Carats (28 56/64, cost $1,728)	0.576
Total	$1.676

Cost in 1907 (3,667 Ft. Drilled).

	Per lin ft.
Labor	$0.715
Power	0.280
Repairs, oil, etc.	0.100
Carats (30 47/64, cost $2,323)	0.633
Total	$1.728

Cost in March, 1907 (540 Ft. Drilled).

	Per lin ft.
Labor	$0.492
Power	0.099
Repairs, etc.	0.049
Carats (2 37/64, cost $219)	0.405
Total	$1.045

Mr. Keffer estimates 16% per year will cover the interest and de-

preciation, or $240 per year to be added to the costs above given, or about 8 cts. per lin. ft. of hole when 3,000 ft. are drilled per year.

Costs of Calyx Core and Diamond Drill Borings, Nova Scotia.*— To further the interests of the mining industry in Nova Scotia the Department of Mines of that province has since 1900 owned and operated a number of core drills for prospecting purposes. In the report of the department for 1908 there are given a summary of the depths of holes bored and the cost of the work for each year from 1900 to 1908, inclusive, and also the itemized cost of the work done during 1908. The following data are compiled from these records.

During 1908 the department had 5 drills in operation, 2 of the Sullivan diamond pattern and 3 of the Calyx shot type. The work of these drills is given as follows:

Drill No. 5.—This was a steam Calyx drill, producing a 6-in. core; its work comprised two holes in the Cape Breton coal measures, one 769½ ft. deep and one 1,170 ft. 11 ins. deep.

The first hole, 769½ ft. deep, was through sandstone, shale and coal. Work was begun Jan. 15, 1908, and the hole was finished March 21, 1908. The average rate of drilling was 0.6 ft. of hole per hour; the maximum rate was 3 ft. of hole per hour. The boring was done with a double shift. The cost of the hole was as follows.

Item.	Total.	Per ft.
Labor including truckage	$ 664	$0.862
Management	241	0.313
Coal	171	0.222
Light, oil, waste, etc.	7	0.009
Shot	56	0.072
Gravel	3	0.004
Lumber, etc.	30	0.040
Casing pipe	5	0.006
Totals	$1,177	$1.528

The second hole, 1,170 ft. 11 ins. deep, was, like the first, through sandstone, shale and coal. Work was begun March 30, 1908, and the hole was finished July 11, 1908. The average rate of drilling was 0.58 ft. per hour and the maximum rate was 3 ft. per hour through sandstone. The boring was done with a double shift. The cost of the hole was as follows:

Item.	Total.	Per ft.
Labor including truckage	$ 995	$0.849
Management	331	0.282
Coal	200	0.171
Light, oil, waste, etc	8	0.007
Shot	68	0.058
Gravel	5	0.004
Lumber	15	0.013
Casing pipe	14	0.012
Short bits and core barrels	168	0.143
Totals	$1,804	$1.539

Drill No. 2.—This was a steam diamond drill, producing a

*Engineering-Contracting, July 28, 1909.

15/16-in. core; its work comprised 6 holes in the Nova Scotia coal measures, 1 at Merigomish, Picton County, and 5 near New Glasgow.

At Merigomish the hole was through red and gray sandstone and shale and was 536 ft. deep. Work was commenced Sept. 18 and the hole was finished Oct. 30, 1907. The average rate of drilling was 1.46 ft. per hour, and the maximum rate was 4 ft. 8 ins. per hour in gray sandstone. The boring was done with a single shift. The cost of the hole was as follows:

Item.	Total.	Per ft.
Labor, including freight and truckage..	$ 133	$0.248
Management	245	0.457
Fuel	11	0.021
Light, oil, waste, etc.	1	0.002
Carbon wear	5	0.009
Lumber	2	0.004
Core lifters and bits	13	0.024
Totals	$410	$0.765

Details of the drilling of only 4 of the holes sunk at New Glasgow are given. The rock penetrated was gray sandstone and shale and black shale, with frequent hard bands.

Hole No. 1, 909 ft. deep, was begun Dec. 9, 1907, and finished Feb. 14, 1908, boring single shift. The average rate of drilling was 1.4 ft. per hour and the maximum rate was 5 ft. in one hour in hard gray standstone. The cost of the hole was as follows:

Item.	Total.	Per ft.
Labor, including freight	$131	$0.144
Management	336	0.369
Coal	36	0.040
Light, oil, waste, etc.	6	0.007
Carbon wear	2	0.002
Lumber	17	0.019
Casing, pump, pipe, etc.	33	0.036
Core lifters and bits	21	0.023
Totals	$582	$0.640

Hole No. 2, 842 ft. deep, was begun March 4 and finished May 30, 1908, working single shift. The average rate of drilling was 1.2 ft. per hour and the maximum rate was 3 ft. 6 ins. per hour in gray shale. The cost of the hole was as follows:

Item.	Total.	Per ft.
Labor, including freight	$130	$0.154
Management	364	0.431
Fuel	30	0.036
Light, oil, waste, etc.	55	0.065
Steel shot	4	0.004
Blank bits, core lifters, shells, etc.	32	0.038
Repairs to engine	20	0.023
Totals	$635	$0.751

Hole No. 3, 646 ft. deep, was begun June 11 and finished Aug. 4, 1908, working a single shift. The average rate of drilling was

1.4 ft. per hour and the maximum rate was 5 ft. per hour in coal. The cost of the hole was as follows:

Item.	Total.	Per ft.
Labor	$ 80	$0.124
Management	249	0.385
Fuel	21	0.032
Oil, waste, etc.	9	0.014
Carbon wear	20	0.031
Core lifters, bits, core shells	13	0.020
Totals	$392	$0.606

Hole No. 4, 500 ft. deep, was begun Aug. 11 and finished Sept. 19, 1908, working a single shift. The average rate of drilling was 1.5 ft. per hour and the maximum rate was 5 ft. in one hour in gray sandstone. The cost of the hole was as follows:

Item.	Total.	Per ft.
Labor, including truckage	$ 67	$0.134
Management	180	0.360
Fuel	15	0.030
Light, oil, waste, etc.	4	0.008
Carbon wear	31	0.062
Black bits, core lifters, steel shoes	15	0.030
Totals	$312	$0.624

Drill No. 3.—This drill was a hand diamond drill, producing a 15/16-in. core, and its work consisted of boring 6 holes in sandstone, shale and limestone to develop a limestone suitable for the manufacture of cement. The holes were of the following depths:

No. 1	65 ft.	8 ins.
No. 2	30 ft.	1 in.
No. 3	31 ft.	0 ins.
No. 4	44 ft.	6 ins.
No. 5	36 ft.	8 ins.
No. 6	36 ft.	0 ins.
Total	243 ft.	11 ns.

The aggregate cost of the 6 holes was as follows:

Item.	Total.	Per ft.
Labor	$219	$0.857
Management	130	0.532
Freight and truckage	12	0.049
Casing pipe	16	0.068
Carbon wear	123	0.504
Totals	$500	$2.007

This same drill was employed to sink one hole in the coal measures, as follows: The hole was 134½ ft. deep, through shale and sandstone; work was begun July 22 and the hole was finished Aug. 12, 1908, working a single shift. The average rate of drilling was 0.74 ft. per hour and the maximum rate was 1 ft. 3 ins. in one hour. The cost of the hole was as follows:

Item.	Total.	Per ft.
Labor	$107	$0.798
Management	50	0.363
Light, oil, waste, etc.	0.55	0.004
Carbon wear	61	0.455
Freight, truckage, repairs, etc.	36	0.267
Totals	$254	$1.887

Drill No. 6.—This drill was a steam Calyx drill, producing a 6-in. core. It was employed in putting down four holes in the Cape Breton coal measures, as follows:

Hole No. 1 was begun Feb. 27 and finished April 13, 1908, working double shift. The average rate of progress was 2⅛ ft. per hour and the maximum rate was 6½ ft. in one hour. The hole was 424½ ft. deep and its cost was as follows:

Item.	Total.	Per ft.
Labor, including freight and truckage...	$294	$0.691
Management	150	0.353
Coal	35	0.083
Light, oil, waste, etc.	6	0.014
Shot	18	0.042
Gravel	3	0.007
Lumber	45	0.106
Totals	$551	$1.296

Hole No. 2, 208½ ft. deep, was begun May 20 and was finished May 30, 1908. The average rate of drilling was 1 ft. per hour and the maximum rate was 5¾ ft. per hour. A double shift was worked. The cost of the hole was as follows:

Item.	Total.	Per ft.
Labor, including freight and truckage...	$127	$0.612
Management	33	0.158
Fuel	15	0.072
Light, oil, waste, etc.	2	0.009
Shot	10	0.048
Gravel	1	0.005
Lumber	12	0.058
Casing	5	0.024
Totals	$205	$0.986

Hole No. 3, 367 ft. deep, was begun June 4 and finished June 27, 1908, working double shift. The average rate of drifting was 0.9 ft. per hour and the maximum rate was 8 ft. in one hour with cutters. The cost of the hole was as follows:

Item.	Total.	Per ft.
Labor, including freight and truckage...	$272	$0.741
Management	75	0.204
Fuel	21	0.057
Light, oil, waste, etc.	5	0.013
Shot	27	0.073
Lumber	8	0.022
Shot bits	7	0.019
Totals	$415	$1.129

Hole No. 4, 502 ft. deep, was begun on July 8 and was finished on July 29, 1908, working double shift. The average rate of drilling was 1.2 ft. per hour and the maximum rate was 8 ft. in one hour with shot. The cost of the hole was as follows:

Item.	Total.	Per ft.
Labor, including truckage	$251	$0.500
Management	72	0.143
Fuel	22	0.043
Light, oil, waste, etc.	4	0.008
Shot	15	0.029
Lumber	7	0.013
Pumping water	80	0.159
Shot barrels used	15	0.029
Totals	$466	$0.924

In presenting these results we have computed and added the columns of costs per foot drilled. The report says:

The average cost per foot for boring by drills was $1.06. The cost per foot for all boring by diamond drills was 80½ cents, and by Calyx drills $1.34. The carbon cost per foot in boring by diamond drills was $0.077, and the shot-cost per foot by Calyx drills, $0.056. These costs compared with last year's results were as follows:

	1907.	1908.	Inc. or Dec.
Cost per foot for all boring	$1.23	$1.06	Dec. 17c
Cost per foot for all Calyx boring	1.71	1.34	Dec. 31c
Cost per foot for all diamond boring	.73	.845	Inc. 11c
Shot-cost per foot boring by Calyx drills	.047	.056	Inc. .009c
Carbon cost per foot boring by diamond	.0129	.077	Inc. .041c

Cost of Core Drilling With a Well Driller.*—In this article we give the cost of drilling holes through rock with a well-drilling machine. Holes Nos. 1 and 2 were holes from which cores were taken, being put down through limestone at Paris, Ky., for the Blue Grass Mining and Development Co. For these two holes a Cyclone steam four-core drill, class E 1, was used, taking a 3¼-in. core. This drill will take cores of 2¼, 3¼ and 4⅛ ins., to a depth of 300 ft. It is the lightest four-core drill made by the Cyclone Co., of Orrville, Ohio. Equipped ready for work, it is sold for less than $1,000, but for our purpose of estimating depreciation and interest on the machine we will consider the price as $1,000, as this figure will cover the freight and other incidental expenses of buying the machine. This machine can be operated by a drill runner and one assistant.

Hole No. 1.—This hole was entirely in limestone and was drilled to a depth of 104 ft. in 50 hrs. actual time of running the machine; the average rate of drilling per hour was 2 ft. 1 in. The men worked more than 50 hrs., the actual time they worked being charged against the hole. The cost was:

Moving drill	$ 3.50
Coal	4.85
Water	3.00
Driller, 60 hrs. @ $0.50	30.00
Helper, 66 hrs. @ $0.15	9.90
Supplies, shot and bits	5.00
Depreciation, repairs and interest per day assumed at $1.50	9.00
	$64.25

This gives a cost per lineal foot of hole for each item as follows:

Moving drill	$0.03
Coal	.05
Water	.03
Labor	.38
Supplies	.05
Depreciation, repairs and interest	.08
Total	$0.62

Hole No. 2.—This hole was 158 ft. through limestone, 80 hrs.

*Engineering-Contracting, Sept. 9, 1908.

being consumed in drilling it. This meant a rate per hour of about 2 ft. The total cost of the hole was as follows:

Moving drill	$ 3.75
Coal	6.00
Water	4.00
Supplies, shot and bits	10.00
Driller, 80 hrs. @ $0.50	40.00
Helper, 88 hrs. @ $0.15	13.20
Depreciation, repairs and interest, per day assumed at $1.50	12.00
Total	$88.95

This gives a cost per lineal foot of hole for each item as follows:

Moving drill	$0.02
Coal	.04
Water	.03
Labor	.34
Supplies	.06
Depreciation, repairs and interest	.08
Total	$0.57

Holes Nos. 4 and 5 were drilled with cable tools, a No. 4 Cyclone drill being used for putting down a 5-in. hole. The work was done near Arritts, Va., for the Low Moor Iron Co. The No. 4 drill is a standard well-drilling machine, and will sink a hole to a depth of 500 ft. It has an 8-hp. boiler and a 7-hp. engine, mounted on traction wheels, weighing in all over 6,000 lbs. This machine can also be rigged to take cores. Depreciation, repairs and interest on it per day will be about the same as for the other drill. Two men operate it.

Hole No. 3.—This hole was drilled through the following materials:

	Ft.
Clay	7
Shale	113
Cap rock (disintegrated)	8
Sandstone	14
Total	142

The time consumed in drilling this was 32 hrs., making a rate of 4 ft. 5 ins. per hour. The cost of the work was as follows:

Coal	$ 4.00
Water	2.40
Driller, 40 hrs. @ $0.20	8.00
Helper, 40 hrs. @ $0.15	6.00
Depreciation, repairs and interest per day, assumed at $1.50	6.00
Total	$26.40

This includes moving the machine. The cost per lineal ft. for each item was:

Coal	$0.03
Water	.02
Labor	.10
Depreciation, repairs and interest	.04
Total	$0.19

Hole No. 4.—This hole was 67 ft. deep, being drilled through the following materials:

	Ft.
Shale	25
Cap rock	2
Ore	10
Sandstone	16
Flint	9
Total	67

Thirteen hours were consumed in drilling this hole, making a rate of progress of 5 ft. and 1 in. per hour. The cost of the work was:

Coal	$ 1.00
Water	.30
Driller, 20 hrs. @ $0.20	4.00
Helper, 20 hrs. @ $0.15	3.00
Depreciation, repairs and interest, per day $1.50	3.00
Total	$11.30

This gives a detail cost per lineal foot of the following:

Coal	$0.015
Water	0.005
Labor	0.100
Depreciation, repairs and interest	0.040
Total	$0.160

All these holes, it will be noticed, were through soft rock, but the costs for the work are very reasonable.

Cost of Diamond Drill and Wash Borings Near New York City.*—Mr. F. Lavis is author of the following.—The following costs of making diamond drill borings were obtained on work in New York City in the fall of 1905. The work was started in October and ran through to the early part of January, there being more or less delay during the latter part of the work (on the diamond borings) due to snow and ice.

The average depth of the holes was about 40 ft., partly in earth and partly in rock, the depth of the latter below the surface varying from 2 to 25 ft., and it being generally overlaid by more or less fine sand. A 2½-in. wrought iron pipe casing was sunk to the rock by a separate crew by the wash method and firmly seated thereon. A 1¼-in. core was obtained of the rock and samples of the washings were taken and preserved in glass jars. The rock was the ordinary New York gneiss and mica schist, which affords easy drilling where seams are not encountered which tend the drill off line and bind the bit.

The crew of the wash machine consisted of 1 foreman at $3 per day and of 3 laborers at $2 per day. A proportion of the superintendence, water supply, watchman, etc., was also charged to this part of the work. This crew sank all the casings to the rock ready for the diamond machine, the work occupying about 15 working days.

*_Engineering-Contracting_, Jan. 9, 1907.

Power for the diamond drill was furnished by a small upright boiler and much time was wasted in shifting the boiler and drill apparatus from one hole to another; had these been both mounted on wheels the expense for drilling would have been cut down at least 10 per cent and probably more. After the first two moves had been made an extra laborer (sometimes two) was put on during the time of moving at $2 a day, with the result that the time was cut down half, from 12 to 16 hours' actual working time to 6 or 8.

A superintendent, who also set all the diamonds, devoted about half his time to the work and was paid $100 per month, and $100 per month rent was paid for the use of the diamond drilling machine. The boiler and wash boring outfit were on hand, having been used previously, and no cost is included for their use. The costs do include an allowance for all pipe used, cost of fuel and other materials and of repairs to diamond machine on completion of work, and new grate bars for the boiler.

The pay-roll was as follows:

1 Superintendent (½ time)	$100.00 per month
Rent of machine	100.00 per month
1 Foreman	3.50 per day
1 Rigger	2.25 per day
2 Laborers	2.20 per day
1 Night watchman	1.50 per day
1 Inspector of city water department	3.00 per day

Water was obtained from the city hydrants and cost about $25 for permits, etc., besides the $3 per day for the inspector.

The costs shown below are considered quite low (at least $1 per ft. less than usual), this being due to a large extent to the very small abrasion of the diamonds. This latter is a most important matter and the favorable results in this case, the loss in some holes being as little as ⅛ carat, and seldom over ⅝, was due to the fact that stones were available which had been previously used (and therefore tested), and that the superintendent who set the stones was an expert at this work. With diamonds at $60 per carat, the importance of properly selected stones, skilful setting and manipulation is apparent.

The following is a summary of the cost:

WASH BORINGS, 206.8 LIN. FT.

	Total.	Per lin. ft.
Labor	$ 276.92	$1.34
Engineering	35.00	0.17
Total	$ 311.92	$1.51

DIAMOND DRILL BORINGS, 460.9 LIN. FT.

	Total.	Per lin. ft.
Labor	$1,888.73	$4.09
Engineering	315.00	0.69
Total	$2,203.73	$4.78

DIAMOND DRILL AND WASH BORINGS, 667.7 LIN. FT.

	Total.	Per lin. ft.
Labor	$2,165.65	$3.25
Engineering	350.00	0.52
Total	$2,515.65	$3.77

Rock Excavating Using Well Drillers.*—Mr. R. M. Hulbert is author of the following.—The quarries of the Atlas Portland Cement Company at Northampton, Pa., are two in number and are situated close to the works of the company. No. 1 quarry is the nearest to the works and is 1,600 to 1,800 ft. long on the face. No. 2 quarry is at a distance of a mile or so from the works and is approximately 1,000 ft. long on the face. These faces range from 42 to 100 ft. in height.

The rock was formerly excavated by benches, i. e., steam or compressed air rock drills were used for drilling holes 20 ft. deep which were charged with dynamite and blasted. The dislodged rock was cleaned up by hand labor after which the drills were again set up and the process repeated. In this way the face of the quarry was removed by three benches, all material being carried away in standard gage freight cars running on tracks laid on the bottom bench, or floor of the quarry.

The drills used for this part of the work were ordinary compressed air rock drills capable of drilling holes 20 ft. in depth with a bottom diameter of 2¼ ins. It was thought that by drilling holes below grade and blasting larger quantities of rock at a time, the cost of handling the excavated material would be materially reduced, all hand labor being practically eliminated and the rock removed by steam shovels running on railroad tracks on the floor of the quarry. It was therefore decided to introduce well drills for this work in place of the rock drills formerly used and the results achieved have more than warranted the change.

The character of the rock, however, makes the work of drilling with well drills of an exceedingly difficult nature as this limestone is not only hard and tough but is honeycombed with seams running at every conceivable angle. In spite of this handicap the drills are averaging approximately 1½ ft. per hour taking into consideration all delays due to blasting, sharpening steels and for other purposes. There are seven drills actually engaged on the work and these are not only able to keep four steam shovels busy in the two quarries, but have drilled many holes ahead. As a general rule, however, it has been found that drilling holes ahead does not always pay as the magnitude of the blasts often throws some of the holes out of plumb and discretion has to be exercised in planning ahead on this part of the work. The drills were manufactured by the Star Drilling Machine Co. of Akron, Ohio.

It sometimes happens that well drilling machines cannot be used to advantage, and an instance of this is to be found in the case of quarry No. 2 of the Atlas plant. Here the entrance to the quarry consists of a narrow opening with high vertical faces on

*Engineering-Contracting, June 5, 1907.

each side. It would be obviously impracticable to widen this opening by means of heavy blasts as by so doing there would be danger of closing up the opening, it being a singular fact that in blasts of this character, the material at the base of the hole is blown outward to a considerable distance, while that at the top settles down vertically and is scarcely thrown out at all. In the case of quarry No. 2 of the Atlas plant, the narrow entrance is being widened by the bench method, eight compressed air rock drills being used. As soon as the face is moved back far enough, however, well drills will be substituted and the holes drilled to grade.

At both quarries the holes are drilled at a distance of 20 ft. from the face and approximately 18 ft. apart, it being the customary practice to space these holes by moving the machine a distance forward equal to its own length, which in this case is about 18 ft. In No. 1 quarry there are two well drilling machines, operating on compressed air and working in two shifts of 10 to 13 hrs. each. Besides these there are the eight compressed air rock drills engaged in opening up the entrance by the bench method. In No. 2 quarry there are five well drills operated by steam generated in a 135-hp. central boiler plant. The steam pressure is maintained at 110 lbs. except when blasting occurs, at which times it is lowered to 85 lbs., as it was found that the detonation of a heavy blast tended to "start" the tubes in the boiler if the pressure was not reduced. A 3-in. steam line leads from the boiler plant to the drills, but this line can also be used for compressed air if desired and, in fact, compressed air is used to operate the drills during the night shift. Of course, it is impossible to install a very high class steam plant for this work owing to the fact that there is no element of permanency in the installation. The plant has already been moved twice and will probably have to be moved again within the next twelve months. In spite of this fact, however, very good economy is obtained, care being taken to thoroughly lag the steam lines which are, in no case, more than 300 ft. in length.

The depth of holes in this quarry ranges from 45 to 85 ft., the diameter being 5 ins., and it is the usual practice where holes are only 45 ft. deep, to drill them with one bit, the wearing away of the gage being in about the right proportion to the depth of hole to do away with the need of changing steels. In the deeper holes, bits are changed at regular intervals until the last 35 ft. is reached when one bit is used to the bottom. As a general rule, however, it might be said that drills are sharpened every 10 ft.

The very difficult nature of the ground and the fact that frequent stops have to be made to straighten holes and during blasting, makes the average of 1½ ft. per hour, taking into consideration all delays, a very good one. But it must be remembered that the real element of economy is not so much in the speed of drilling as in the greater efficiency in blasting, more rock being displaced by blasting holes drilled below grade than by successive lifts of 20 to 25 ft. In working in these benches each bench has to be cleaned off by hand labor, except the final one at grade which may be cleaned off by steam shovels.

Cost of An Artesian Well.*—Mr. Wm. G. Fargo, consulting engineer, of Jackson, Mich., has furnished us with the following data regarding the cost of an artesian well:

The well was sunk at the Lansing, Mich., sub-station of the Commonwealth Power Co. It was 3 ins. in diameter and 107 ft. deep. Of this depth 50 ft. was through soft material and 57 ft. through rock. This meant that only 50 ft. needed sheathing, which was done by 50 ft. of 3-in. pipe at a cost of 32 cts. per foot, making a total cost for pipe of $16.

The well drilling machine, a small one, was hired for the work, 60 cts. per hour being paid for the use of the machine and the services of the man to run it. One laborer assisted this man in drilling the well. Record was not kept of the fuel used.

The cost was as follows:

71 hours' use of machine at $0.60	$42.60
69 hours' labor at $0.20	13.80
58 ft. 3-in. pipe at $0.32	16.00
Total	$72.40

This gives a cost per lineal foot of well of 67.6 cts.

For other data on the methods and costs of sinking wells see the index under "Well Drilling."

Cost of Drilling Limestone With Well Driller, For a Quarry.†—There has been some demand in large blasting work for a well drilling machine operated by electric power instead of by the usual boiler and engine. Where blasting operations are conducted within city limits some inconvenience and a large item of expense are represented in providing a licensed engineer, as required by law, for each separate steam driven machine. There is also economy in generating all power at a central plant. In some locations also it is impossible to use a boiler. To meet these difficulties some contractors have operated a number of drillers from one centrally located steam or compressed air plant, carrying pipes to the several machines. These last plans, however, involve the constant relaying of steam or air lines with bother and loss of power from condensations, leakage, etc. To obviate these and other disadvantages connected with the steam machine as used in certain classes of work, the Keystone Quarry Drill Co., Beaver Falls, Pa., has designed an electric driven machine and one of these has now been at work for some time in the Belleville, Ill., quarries of James & A. C. O'Laughlin, of Chicago, Ill. The following data relate to this machine and its work:

The machine is equipped with a 10-hp. specially geared motor placed over the rear truck and belted to the drilling mechanism, which is back geared and balanced so as to run lightly and smoothly. The controller box is located at the front of the machine close to the driller's hand. The drilling tools comprise a stem weighing about 1,000 lbs., a drill bit weighing 150 lbs., and a rope socket weighing about 50 lbs., or about 1,200 lbs. together. The bit cuts a 5⅝-in.

*Engineering-Contracting, April 8, 1908.

†Engineering-Contracting, July 21, 1909.

hole and the stem is 3¾ ins. in diameter and 22 ft. long. As the stroke is from 30 to 36 ins., a blow of from 3,000 to 3,500 ft. lbs. is obtained at each stroke. The machine is built with gear hoist, capacity 500 ft., or with friction hoist, capacity 350 ft. The makers consider the latter style of machine probably the best for quarry and rock cut work where the tools are being constantly raised and lowered as in tamping a charge, and where the holes will rarely exceed 150 ft. in depth. This machine is made with a traction attachment for self propulsion if desired; while it is impracticable to move the machine over great distances by this means, on account of carrying along the electric feed wires, for short moves from hole to hole or from one side of the quarry to the other it has been found to be of great advantage.

In operating at the full speed of the motor the tools make about 60 strokes per minute. As the hole becomes deeper or clogged with cuttings, before sand pumping, the rapidity of the stroke is gradually reduced to say 50 strokes per minute in order that the cutting bit may deliver its blow with best effect. This change of speed is produced by reducing the speed of the motor.

Besides doing the drilling this machine is used for loading the holes. For this service the regular drilling bit is removed and in its place a wooden rammer is placed on the drill stem. From 5 to 8 sticks of dynamite having been dropped into the hole the drilling tool is lowered after them, forcing them to the bottom. The tools are then withdrawn and the operation repeated until all the charge is placed. The placing of the firing cap and wires and the tamping are done by hand.

At the James & A. C. O'Laughlin quarry limestone is being drilled and blasted for crushed stone. The machine was furnished by the makers on the guarantee to drill to a depth of 60 ft., at the rate of 40 ft. per 10-hour day, or 4 ft. per hour. In the tests made on delivery of the machine the following records were obtained: The machine was set up on June 5 at 5 o'clock and ran for 1 hour, drilling 9 ft. of hole. From the following Monday morning until Friday forenoon, something over 4 days, working 10 hours a day, four 66 ft. holes or 264 ft. of hole were drilled. In the following week four holes 105 ft. deep or 420 ft. of hole were drilled. These figures are furnished by the Keystone Quarry Drill Co. In a letter to us the James & A. C. O'Laughlin Co. state that in actual work the machine is averaging 40 ft. of 5⅝-in. hole per 10-hour day, and is giving good satisfaction. The daily operating expenses are as follows:

One drill runner at $2.50	$2.50
One helper at $2	2.00
Cost of electric current	2.00
Oil, drill sharpening, etc	1.50
Total per day	$8.00

This gives a cost per foot of hole drilled of 20 cts.

In a blast of four 5⅝-in. holes 66 ft. deep, the charge consisted of 5,500 lbs. of dynamite packed solidly in the holes to within 25 ft. of the top and then tamped with screenings. The quarry manager

estimated that 20,000 cu. yds. of stone were thrown down by this blast. The breast was 105 ft. high, and, as will be seen, the holes were put down only about half way. In recent work the holes have been drilled the full depth of the breast.

Cost of Drilling Rock With a Well Drilling Machine.*—The following is a record of some holes drilled, and the cost of drilling them, at Musselishell and Roundup, Montana, for the Republic Coal Co. of Chicago, Ill.

The work was done with a No. 2 Cyclone drill, manufactured by the Cyclone Drill Co., of Orrville, Ohio. The machine was equipped with hollow rod tools. This machine is meant to drill holes from 500 to 700 ft. deep; it is equipped with a 7-hp. engine run with gasoline. Holes from 23 ft. to 517 ft. were drilled. The bits used were 2½ ins. Two men, the drill runner and a helper, were employed on the machine. The work was done in prospecting. The record of each hole is given in the table.

RECORD OF HOLES DRILLED.

Hole No.	Depth.	Average drilled per shift.	Material.
1	391 ft. 7 in.	39 ft. 1 in	Shale and sandstone.
2	293 ft.	36 ft. 7 in.	Shale and sandstone.
3	284 ft.	47 ft. 4 in.	Shale and sandstone.
4	347 ft.	49 ft. 7 in.	Shale and sandstone.
5	103 ft.	51 ft. 6 in.	Shale and sandstone.
6	297 ft.	42 ft. 5 in.	Shale and sandstone.
7	36 ft. 6 in.	52 ft.	Soil and gravel.
8	23 ft. 11 in.	32 ft.	Soil, gravel, shale.
9	51 ft. 8 in.	47 ft. 8 in.	Soil, gravel, shale.
10	27 ft. 3 in.	38 ft.	Soil, gravel, shale.
11	53 ft. 5 in.	30 ft.	Soil, gravel, shale.
12	517 ft.	36 ft. 11 in.	Shale and sandstone.
13	463 ft.	57 ft. 5 in.	Shale and sandstone.
Total...	2,885 ft. 4 in.	41 ft. 10 in.	

In all, 69 days were worked, making the average nearly 42 ft. drilled per 10 lb. shift, as shown in the table.

The cost of the work is shown below. A two horse team was used to haul water and other supplies. The machine used 4 gals. of gasoline per day. It will be noticed that the cost of the team was nearly 50 per cent of the total cost.

Drill Runner, 69 days @ $2.50	$172.50
Helper, 69 days @ $2.00	138.00
Team, 69 days @ $4.00	276.00
276 gals. gasoline @ 12 cents	33.12
Total	$619.62

This gives a cost of 21½ cents per ft. of hole. To this should be added an allowance for plant and superintendence. It will be noticed that some of the holes are very shallow, thus necessitating frequent moves of the machine.

Cost of Drilling Copper Ore With Well Drillers.†—The following costs on drilling and blasting, and the methods of mining copper ore with a steam shovel at the Copper Flat Mines in Nevada, are abstracted from "Mines and Minerals."

**Engineering-Contracting*, Nov. 18, 1908.

†*Engineering-Contracting*, Sept. 9, 1908.

The ore lies in a flat, and is estimated to be more than 200 ft. in depth, the ore occurring in a porphyry. It is capped with earth and rock to a depth of about 87 ft. This stripping and the ore are worked in trenches 50 ft. deep.

Cost of Drilling.—The holes are put down by two Keystone No. 5 traction drills, owned by the mining company and kept continually at work drilling to loosen ground for the steam shovels. The Keystone No. 5 machine is built specially for mineral prospecting and mine work, it being the largest machine made by the Keystone Driller Co., of Beaver Falls, Pa. The boiler is mounted on the same trucks with the engine, and the machine is propelled on traction wheels. The engine is 14-hp. The derrick is 34 ft. high. The machine weighs 16,000 lbs. and costs, without tools or equipment, $1,375. This machine will drill holes from 1,000 to 1,200 ft. deep.

The drills use a 5⅝-in. bit which gives a hole about 6½ ins. in diameter, and the holes are put down to a depth of about 60 ft. The holes are spaced on 35-ft. centers and are back from the breast of the bench 40 ft. This is the usual spacing; however, where hard masses of tough carbonate ores are encountered, holes are about 15 ft. apart and 15 ft. from the breast. Each machine requires a driller, who is paid $4 per day, and an assistant, who is paid $3 per day. Nine-hour shifts are worked. A 60-ft. hole is put down in two shifts, or 18 hrs., thus 3 ft. and 5 ins. of hole is drilled per hour. For each hole the boiler burns 1⅝ cords of wood, costing $6 per cord. The cost of drilling one 60 ft. hole is as follows:

Driller, 2 days	$ 8.00
Assistant, 2 days	6.00
Fuel	10.00
Oil and waste	0.55
Extra parts, repairs, renewals	2.15
Rope wear per hole	3.50
Estimated interest and depreciation	2.00
Total	$32.20

This gives a cost per lineal foot of hole as follows:

	Per lin. ft.
Labor	$0.23
Fuel	0.17
Oil and waste	0.01
Repairs and renewals	0.04
Rope wear	0.05
Interest and depreciation	0.03
Total	$0.53

Cost of Blasting.—In blasting any material the amount of explosives used naturally varies with the location and depth of holes and with the hardness of the materials. However, the average amount of explosives used in this work was obtained, and was as follows: The holes were sprung with two 50-lb. boxes of 40 per cent dynamite, costing $15.40 for 100 lbs. Then the hole was reamed out, and from 20 to 30 kegs of black powder were used in the blast, the average being 25 kegs or 625 lbs., costing $2.25 per keg. This gave a total cost for explosives of $71.65.

Assuming that a block, 35x40x60 ft., is broken by the hole, we have a total of 3,111 cu. yds. of material moved by the black powder per cu. yd. of material, or 0.23 lbs. of explosives per cu. yd. for both springing and blasting. This is a very small amount of powder to be used for rock blasting. The total cost per cu. yd. for drilling and blasting was:

	Per cu. yd.
Drilling	$0.010
Blasting	0.023
Total	$0.033

This cost of 3⅓ cts. per cu. yd. is very low for the hard material. On the other hand, for the earth capping this cost is a little high; however, the cost given is an average for the two materials.

Steam Shovel Work.—Three 95-ton and one 70-ton Bucyrus steam shovels are used to load the blasted material. The dippers are equipped with manganese steel teeth, the repairs on them being very light. The shovels load the stripping into two wayside dump cars of 3¼ cu. yds. capacity. The trains are pulled by 45-ton locomotives. Ten cars make up a train.

The ore is loaded into 50-ton bottom-dump cars for direct transportation to the concentrator. The ore is hauled by the railroad company and not by the mining company. Exact records of the cost of the steam shovel work are not available, but the work done by them in the first six months shows that the cost is much less than other methods in vogue in that part of the west, the saving being enough to make profitable the mining of low grade ores with this method, when it is not possible to make a profit on higher grade ores with other methods.

Cost of Tunneling, Shaft Sinking and Mining, Cross-References.—Data on these subjects will be found in the following sections of this book: Railways, and Sewers. Consult the index under "Tunnels," "Shafts." Consult Gillette's "Rock Excavation."

Cost of Subaqueous Rock Excavation.—On jobs of size sufficient to warrant the installation of a good plant, the cost of drilling, blasting and dredging rock of the consistency of hard limestone averages about $2.50 per cu. yd., although I have records of work where the actual cost (including plant repairs, interest, and depreciation), was less than $2 per cu. yd. For discussion of methods and for cost records, see my book on "Rock Excavation."

Costs of Chamber Blasting.—By this method, one or more small tunnels are driven into the face of a rock hill that is to be quarried. Generally such a tunnel runs in not more than 50 ft., and then it branches right and left, forming a *T*. Heavy charges of black powder or of Judson are placed in the branches of *T*, and fired. As much as 350,000 tons of rock have thus been shattered at one blast. Costs as low as 3½ cts. per cu. yd. (solid) are on record for breaking rock in this way. See Gillettes' "Rock Excavation."

A similar method has often been used on a smaller scale for blasting hardpan that was so full of boulders as to make drilling very expensive.

SECTION IV.

ROADS, PAVEMENTS, WALKS, ETC.

Definitions.—*Asphalt Pavements.*—In the broad sense of the term, an asphalt pavement is any pavement composed of mineral particles cemented together with asphalt. This definition includes ordinary asphalt pavement, Bitulithic, Petrolithic, etc., as well as "oiled roads" of the California type, also "asphalt macadam." All these, in reality, are species of asphalt pavement. Asphalt pavement, however, is a term generally used in a narrower sense, and applies usually to a class of pavement (sometimes called "sheet asphalt" to distinguish it from "asphalt block" pavement), the wearing coat of which is composed of sand, limestone dust and asphalt, mixed hot in a mechanical mixer, laid upon a "binder course" and rolled. The "binder course," or "binder" is usually a thin layer of finely broken stone mixed hot with asphalt, spread upon a concrete base and rolled. However, it is frequently the practice to use only a "naphtha binder," which is merely a coat of what might be called an asphalt paint applied with brushes to the surface of the concrete base. In either case, the object of the "binder" is to prevent the asphalt wearing surface from creeping along or peeling away from the concrete base.

"Lake asphalt" is an asphalt obtained from Trinidad Lake, or other similar deposit.

A "rock asphalt pavement" is one made of rock which is found in deposits that are impregnated with asphalt.

An "asphalt block pavement" is made of blocks or bricks, composed of graded sizes of broken stone, sandstone dust mixed with asphalt, and compacted in a block machine under great pressure. The standard size for blocks is 3 x 5 x 12 ins. (See Peckham's "Solid Bitumens," p. 310.)

Barrel.—The most common size of barrel in which asphaltic oil is shipped holds 42 gals. The standard size of tar barrel appears to be 52 gals.

Base.—The artificial foundation on which the "wearing coat" of a pavement rests. The most commonly used base is concrete, generally 6 ins. thick. The word base is preferable to the word foundation.

Belgian Block Pavement.—A stone block pavement, the stones being rectangular in shape and of a size about 3 x 6 x 10 ins., although varying more or less, except in the matter of thickness which is usually 6 ins. Granite and sandstone are about the only

kinds of stone used in America, although trap was formerly used to a considerable extent.

Berm.—The "shoulder" or "wing" of earth between the edge of the paved part of a country road and the edge of the ditch.

Binder.—A term used in several senses: (1) The screenings, or soil, used to bind a macadam road together; (2) the "binder coat" between a concrete base on an asphalt wearing surface (see Asphalt Pavement); (3) any bituminous material used to bind mineral fragments together.

Bitulithic Pavement.—A wearing coat composed of broken stone, sand, stone dust and a bituminous cement, usually asphalt, mixed in a machine, and laid upon a base of concrete or other material.

Bitumen.—No generally accepted definition of this term exists. Peckham's "Solid Bitumens," p. 80, contains the following: "Bitumen, a generic term including substances occurring in nature, in outflows or springs, and in veins, as natural inflammable gas, fluid petroleum, viscous maltha and solid asphaltum and asphaltite. It also occurs saturating and mixed with limestones, sandstones, sand or earthy matter. These mixtures are called asphalte." Asphalt, pitch, tar, etc., are commonly included in the generic term bitumen.

Blind.—A surfacing of screenings or gravel on a macadam road.

Blind Train.—A trench filled with broken stone.

Block Pavement.—A pavement made of stone, brick, wood, or asphalt blocks. Vitrified bricks of large size ($3\frac{1}{4} \times 8\frac{1}{2} \times 4$ ins.) are called "blocks," to distinguish them from bricks of a smaller size ($2\frac{1}{2} \times 8\frac{1}{2} \times 4$ ins).

Bottoming.—The base of a Telford pavement, consisting of large stones set on edge forming a rough pavement. On this "bottoming" is laid the macadam wearing coat, the whole forming a Telford pavement or road.

Box Culvert.—A small culvert with an opening of rectangular shape. Originally such culverts had rubble masonry sidewalls for the sides, cobble pavement for the bottom and slabs of stone ("coverstones"), resting on the sidewalls, for the top. Box culverts are now made entirely of concrete, as a rule.

Box.—The unit of measure of mixed ingredients for an asphalt pavement is commonly the "box" of 9 cu. ft. The amount of compression of the mixture used to make an asphalt wearing coat is variously estimated at 1/6 to ⅓. Hence a 9-cu. ft. "box" of mixture will yield 7½ to 6 cu. ft. of compacted wearing coat, which will make 5 to 4 sq. yds. of wearing coat 2 ins. thick—5 sq. yds. if the shrinkage is only 16⅔%; 4 sq. yds. if the shrinkage is 33⅓% under the roller.

Brick.—Vitrified paving brick are made of selected clay or shale burned so as to produce an exceedingly hard and tough brick.

Broken Stone.—Stone that has passed through a rock crusher (or has been broken to small size with hammers), also called "crushed stone." When it has not been screened into different sizes, it is called "run of crusher," or "crusher run." The smallest size, generally ½ or ¾ down to dust, is called "screenings." Sometimes a

macadam road is called a "broken stone road," but the term macadam is preferable. Broken stone is sometimes called "ballast," which is only objectionable because of possible confusion with the ballast of a railway track.

Catch-Water.—A broad, shallow paved ditch across a road built on a steep grade, for the purpose of diverting surface water to side ditches. In climates where snow accumulates, giving a sharp crown to a road does not serve sufficiently well to divert the melting snow to the side ditches. Hence the use of catch-waters on steep grades where melted snow would follow the wheel tracks down the center of the road and do damage to its surface if not diverted at short intervals.

Cement Curb.—A curb made of concrete faced on the front and top with cement mortar.

Cement Walk.—A footway, or walk, having a concrete base and a cement mortar wearing coat.

Coal Tar.—See Tar.

Cobblestone Pavement.—A pavement of rounded cobbles. Seldom used except for paving gutters.

Corduroy.—A crude road made of split or round logs (usually about 6 ins. diameter) laid side by side, not unlike railway ties spaced so close as to touch one another. For a cheap road over marshy ground, the corduroy road is often used in a timbered country.

Cover Stone—See Box Culvert.

Creosoted Wood Block.—Dried timber blocks impregnated with oil of creosote (dead oil of tar), 16 to 20 lbs. of oil per cu. ft. of timber. Creosote weighs 8.8 lbs. per gal.

Crossing.—A footwalk across a street, usually made of stone slabs.

Crown.—The arch or camber of the surface of a road or street; the transverse profile of a roadway.

Crushed Stone.—See Broken Stone.

Crusher Run.—See Broken Stone.

Culvert.—A waterway under a roadway. See Box Culvert.

Curb.—A miniature retaining wall at the outside of a sidewalk and forming one side of the gutter; an edge stone.

Cushion.—A thin layer of sand or screenings under the wearing coat of blocks (stone, brick, etc.).

Cushion Coat.—A coat of ½-in. of asphaltic mixture upon which the wearing or surface coat of an asphalt pavement is laid. Now replaced by the "binder coat." See Asphalt Pavement.

Flagging, or Flag Stone.—A thin slab of stone for a crosswalk or sidewalk.

Foundation.—The base (usually of concrete) which supports the wearing coat of a pavement; also cinders, gravel, broken stone, or the like, under a cement walk. It is preferable to use the word base when speaking of the concrete foundation of a pavement.

Gage.—The "track" of wagon wheels, measured from center to center of the tires; usually 4 ft. 8 ins. to 5 ft.

Gallon.—The U. S. gallon contains 231 cu. ins. = 0.13368 cu. ft. A cu. ft. contains 7.48 gals. A gallon of water weighs 8.34 lbs.; or 1 lb. of water = 0.12 gals. See Barrel.

Grade.—The rate of per cent. of rise or fall of the longitudinal profile of a road. A 1% grade means a rise of 1 ft. vertical in 100 ft. horizontal. Grade is also a verb, meaning to excavate or fill to grade lines.

Grader.—A "road machine" having a steel blade for leveling, scraping or "drifting" earth. The word "grader" is also applied to an "elevating grader," a machine having a plow that casts the earth upon an endless belt which elevates the earth into a wagon traveling alongside, or deposits it in an embankment alongside.

Granolithic Walk.—A cement walk whose surface coat contains finely broken stone.

Great Square.—An area of 10,000 sq. ft. (or 100 "squares"), sometimes used as the unit of street sweeping. It is preferable to retain the old unit of 1,000 sq. yds. for that purpose, since the sq. yd. is the unit of first cost of pavements.

Grout.—A flowing mortar, either of pure cement and water, or of cement, sand and water. Commonly used for filling the joints of brick pavement; also, in some places, for filling joints of Belgian block pavement.

Grub.—To remove roots and stumps.

Guard Rail.—A fence along an embankment, or a bridge, to prevent vehicles from running over its edge.

Halwood Block.—A paving brick made of "mica shale," clay and sand; size, 3 x 4 x 9 ins.

Hand Rail.—Same as Guard Rail.

Hassam Pavement.—A concrete pavement made by grouting broken stone with Portland cement mortar and rolling with a steam roller.

Hot Stuff.—The hot mixture of sand, stone dust and asphalt, used for making an asphalt pavement.

Leveler.—A machine somewhat similar to a "road machine," but much smaller; used for leveling earth subgrades, also for leveling or spreading the broken stone for a macadam road.

Macadam.—A pavement made of graded sizes of broken stone held together by the mineral colloids of the stone. This "mineral glue or jelly," as the colloids may be called, is not visible, and its binding action was not recognized until the recent investigations of Cushman, Chemist of the Office of Public Roads, U. S. Dept. of Agriculture.

Asphalt macadam is a macadam in which the binder is asphalt. Ditto, tar macadam.

Mastic.—A mixture of bituminous limestone and refined asphalt, formerly much used for sidewalks.

Metal.—The broken stone used for macadam; often called "road metal." Perhaps a better term is ballast. At least it is no more ambiguous.

Mile.—5,280 ft., 1,760 lin. yds. A mile long and 10 ft. wide contains 5,866⅔ sq. yds. = 1.21212+ acres. A mile long and 16 ft. wide contains 9,386.7 sq. yds.

1 mile long x 10 ft. wide x 1 in. deep =	162.96	cu. yds.
1 mile long x 10 ft. wide x 6 ins. deep =	977.76	cu. yds.
1 mile long x 16 ft. wide x 1 in. deep =	260.737	cu. yds.
1 mile long x 16 ft. wide x 4 ins. deep =	1,042.95	cu. yds.
1 mile long x 16 ft. wide x 6 ins deep =	1,564.42	cu. yds.

Oiled Road.—An earth road sprinkled with asphaltic oil so as to form a crust of mineral matter bound together with asphalt. This is the "surface oiled road" originally developed in California, but greatly improved in recent years by mechanical mixing of the asphaltic oil with the soil to a depth of several inches and compacting with a rolling tamper.

Pavement.—A floor-like covering built upon the soil to form a firm, unyielding roadway for wheeled vehicles and animals.

This definition includes any artificial highway covering built upon an earth subgrade, from the cheapest "gravel road" to the most expensive granite block pavement. English engineers have been in the habit of not calling macadam a pavement, but, as macadam performs every function that any pavement performs, there is no logical reason for excluding it from the list of pavements.

Every pavement has three functions to perform:

(1) Distributing concentrated wheel loads over the earth subgrade.

(2) Roofing the earth subgrade so as to prevent its saturation with water.

(3) Giving a hard, clean, smooth (but not slippery) surface that reduces rolling friction.

Pavements generally consist of two parts, (1) a "base" which performs the function of distributing the wheel load, and (2) a wearing coat which sheds rain and provides a durable, smooth surface. The wearing coats commonly used for road and street pavements may be divided into 6 types:

Type 1. Granular minerals bound with mineral glue (or mineral jelly).

Type 2. Granular mineral bound with bitumen.

Type 3. Granular mineral bound with Portland cement.

Type 4. Stone blocks.

Type 5. Wooden blocks.

Type 6. Brick.

By the term "granular mineral" we mean fragments of mineral matter of any size from dust up to fragments as large as hens' eggs, or even larger, whether the fragments have been produced artificially by crushing or pulverizing, or by the forces of nature.

By the term "mineral glue" we mean the "colloids" which Cushman has proved to be the cementing element of rock dust, which causes macadam to bind, and to which the "sticky" properties of clay are attributable.

Type 1 includes:
- (a) Sand-clay roads.
- (b) Gravel roads.
- (c) Shell roads.
- (d) Macadam.

Type 2 includes:
- (a) Oiled roads.
- (b) Tar macadam, or tar concrete.
- (c) Asphalt macadam, or asphalt concrete.
- (d) Asphalt pavement, (1) sheet and (2) block.
- (e) Bitulithic pavement.
- (f) Petrolithic pavement.

Type 3 includes:
- (a) Concrete.
- (b) Macadam grouted with cement (Hassam pavement).

Types 4, 5 and 6 are self explanatory.

Pavers.—Men who lay paving blocks; also the blocks themselves, particularly the small size paving bricks (2½ x 8½ x 4 ins.), as distinguished from the large size called "blocks" (3¼ x 8½ x 4 ins.).

Paving Cement.—A mixture of asphalt tar and still wax.

Petrolithic Pavement.—A pavement made of mineral matter (soil, broken stone or the like) mixed with a bituminous binder (asphaltic oil or tar) and compacted into a uniformly dense mass with a rolling tamper (a roller provided with projecting tampers, feet or "spuds"). Where the traffic is light, natural soil is ploughed up, pulverized and mixed with asphaltic oil, using a road machine and a "cultivator" for mixing. Then it is tamped so as to form a pavement 4 to 8 ins. thick. Where the traffic is heavier, the pavement base is made of the natural soil as just described, but a wearing coat is provided, consisting of broken stone or gravel of graded sizes mixed with the bituminous binder and tamped so as to form a layer 2 to 4 ins. thick. This is often called Petrolithic macadam.

Pitch.—Any tar or asphalt, or mixtures of the same, may be called pitch. The term is not definite. See Peckham's "Solid Bitumens."

Profile.—The line of intersection of a vertical plane with the earth's surface; ordinarily applied to the longitudinal profile of the ground over which a road is to be built. The transverse profile is the cross-section.

Ravel.—When the stones of a macadam road are displaced by traffic, it is said to "ravel."

Right of Way.—The land owned by the public for highway purposes.

Road.—In America the term road is applied only to country highways. In England it is applied also to city streets.

Road Machine.—See Grader.

Road Oil.—A bituminous (generally asphaltic) oil for sprinkling on a road to lay the dust.

Run of Crusher.—See Broken Stone.

Roller.—The ordinary steam roller is a 10 to 15-ton locomotive

with broad-tired wheels. A corrugated roller is generally a horse-drawn roller having several rolling discs on the same axle, discs of large and small diameter alternating so as to produce a "corrugated" appearance. This type of roller is supposed to be more effective than a smooth roller for compacting earth embankments. A tamping roller, or rolling tamper, is a roller having projecting tampers (or feet, or "spuds") which penetrate the loosened earth and begin compacting it from the bottom up.

Sand Cushion.—A thin layer of sand underneath a brick or block pavement. See Cushion.

Scarify.—To pick up or loosen old macadam preparatory to resurfacing it.

Screenings.—The fine product of a rock crusher, usually from dust up to ½ to ¾ in. in size. See Broken Stone.

Shaping.—The process of giving the final finishing to a subgrade, including the rolling of the subgrade.

Shoulder.—See Berm.

Slope Stake.—A stake set to mark the toe of a "fill" (embankment) or the top outer edge of a "cut" (excavation).

Spreader.—See Leveler. A "spreader wagon" is a dump wagon designed to discharge its load in a layer of uniform thickness.

Square.—100 sq. ft.; a unit of area occasionally used in measuring pavements, but one not to be recommended now that the sq. yd. (9 sq. ft.) is the common unit. See Great Square.

Subgrade.—The graded surface of the soil upon which a pavement rests.

Tar.—Coal tar is a by-product in the manufacture of coal gas or coke. See Barrel.

Tarvia.—A refined tar especially made for road use.

Telford.—A pavement consisting of a base, or "bottoming," of large stones set on edge, supporting a wearing coat of ordinary macadam. See Macadam.

Thank You, Ma'am.—A catch-water. See Catch-Water.

Ton.—Unless otherwise stated, the ton of 2,000 lbs. is used in this book. The "gross ton" of 2,240 lbs. is not ordinarily used in America as a unit for broken stone, asphalt, or, indeed, for any road or street material.

Tractive Resistance.—The frictional resistance that a load on wheels offers.

Wearing Coat.—The surface layer or coat of a pavement. See Pavement.

Wings.—See Berm.

Wood Block.—See Creosoted Block.

Vitrified Brick.—See Brick.

Yard.—When the word yard is used in reference to a pavement, the square yard (9 sq. ft.) is usually meant. The lineal yard is never used in America as a unit for road or street work.

Water Table.—A horizontal slab of concrete or stone forming the floor of a gutter next to a curb.

Cross-References to Excavation and Rock Crushing.—Since the principal items of cost of excavating earth and rock are often much the same, whether for a road or for a railway, I have given most of the data on excavation in the Earth Excavation and Embankment Section and in the Rock Excavation Section of this book.

The cost of crushing rock for macadam, concrete, or other purposes, is also given in the Rock Excavation Section. Some examples of the cost of grading roads will be found, however, in this Road and Street Section. See page 332.

Units Used in Measuring Macadam.—Due to the fact that macadam is measured in various ways by different engineers, there has been much confusion in recording costs. The following are some of the different units that engineers have used:

(1) Cu. yd. of consolidated macadam, measured in finished road.

(2) Cu. yd. of loose stone, including screenings, measured in wagons.

(3) Cu. yd. of loose stone, measured, on the road, but not including screenings or binder.

(4) Sq. yd. of consolidated macadam.

(5) Sq. yd. of loose stone (sometimes excluding screenings).

(6) Ton (usually 2,000 lbs., but sometimes 2,240 lbs.) of stone used to make the macadam, usually including the screenings or binder, but not always.

In view of the great uncertainty as to what may be meant by the expression "cubic yard of macadam" or "cubic yard of stone," every writer should be careful to tell exactly what he means.

Of the various units above mentioned, I prefer the first—the cubic yard of completed macadam.

However, the ton of 2,000 lbs. is often a convenient unit for measuring the material in a macadam road, and is also likely to be used extensively. When the ton is used as the unit, care should be taken to give the weight of the loose broken stone per cubic yard, so that conversions can be made.

Since loose broken stone consolidates about 10% when hauled a short distance in a wagon or car, care should be taken to state where the measurement of volume was made.

Macadam roads vary so greatly in thickness, that it is particularly desirable to use the cubic yard of consolidated macadam as the unit, instead of the square yard; but the thickness of the macadam, after compacting, should always be stated, for the per cent of screenings, or binder, aries with the thickness, and the amount of rolling is less per cubic yard for thick macadam than for thin macadam.

Items of Cost of Macadam.—The following are all the items usually involved in macadam construction done by a contractor:

Materials:

Broken stone (coarse).
Screenings, or binder.
Freight on stone and screenings.
Water for sprinkling.

Labor:
- Loading stone and screenings into wagons.
- Hauling stone and screenings.
- Spreading stone (coarse).
- Spreading screenings, or binder.
- Rolling.
- Sprinkling.
- Foreman.

General Expense:
- Superintendent, watchman, waterboy, timekeeper, and clerks, insurance of workmen, etc.

Supplies and Plant:
- Coal for roller.
- Oil and waste for roller.
- Interest, depreciation and repairs on roller.
- Interest, depreciation and repairs on wagons.
- Interest, depreciation and repairs on small tools.

In the foregoing summary, it is assumed that the broken stone and screenings are either purchased, or that, if quarried and crushed by the contractor himself, the cost of quarrying and crushing is kept entirely separate from the cost of building the macadam. The reader will find costs of quarrying and crushing in the section on Rock Excavation and Quarrying.

It is also assumed that the grading, including preparing the subgrade, is likewise kept separately, for to do otherwise leads to great confusion, as the yardage and cost of grading have no relation whatsoever to the yardage of macadam and its cost.

While the size of each particular job should be recorded, stating length, width and thickness of the compacted macadam, writers only confuse their records by giving *total costs* of each of the above items. What a reader desires is *unit costs,* that is the cost of each item in terms of the cubic yard of compacted macadam as the unit. Then, if the writer has stated the total number of cubic yards involved, it is a simple matter of multiplication to arrive at total costs, should anyone desire totals.

Quantity of Stone and Binder Required for Macadam.—About ten years ago I called attention to an error that had been copied in text books from a very early day down to the present, namely the statement that a layer of loose stone 6 ins. thick can be compacted under a roller till it is 4 ins. thick. No such compression is possible, but it often happens that the stone is driven 1 to 2 ins. into the subgrade. On a hard earth subgrade, it never requires more than 1.3 cu. yds. of coarse loose stone (exclusive of the screenings or binder) to make 1 cu. yd. of rolled or compacted stone, and where the stone is very tough the "compression" is even less.

The percentage of binder or screenings required to fill the voids in the rolled stone varies somewhat with the thickness of the macadam. *To ascertain the thickness of the coat of screenings necessary to fill the voids in the rolled stone, divide the thickness of the rolled stone by 4 and add ½ inch.* Thus, for a 6-in. macadam road,

there will be required $(6 \div 4) + \frac{1}{3} = 1\ 5/6$ ins. of screenings. This is equivalent to 0.3 cu. yd. of screenings per cu. yd. of macadam. Therefore, to make a cubic yard of finished 6-in. macadam requires 1.3 cu. yds. of coarse stone and 0.3 cu. yd. of screenings, or 1.6 cu. yds. measured in the wagons to make 1 cu. yd. of compacted macadam. Stated differently:

7.8 ins. of loose stone (½ to 2½-in.) will roll to 6 ins.
1.8 ins. of screenings (less than ½-in) will fill voids.

—

9.6 ins. of loose stone and screenings will make 6 ins. of macadam.

If the stone weighs 2,400 lbs. per cu. yd., we need 1.56 short tons of coarse stone and 0.36 short ton of screenings, a total of 1.92 tons required to make 1 cu. yd. of finished macadam. If the stone is a heavy trap rock, weighing 2,700 lbs. per cu. yd., we need 1.75 short tons of coarse stone and 0.41 short ton of screenings, a total of 2.16 tons per cu. yd. of finished macadam. This estimate, based upon my own records, checks very well with records published by the Massachusetts Highway Commission.

On 2.6 miles of 6-in. New York State macadam, 1,600 cu. yds. of screenings were required to bind 4,000 cu. yds. of macadam rolled in place. This is equivalent to 0.4 cu. yd. of screenings per cu. yd. of macadam, or a depth of 2.4 ins. of loose screenings to bind the 6 ins. of rolled macadam. This large amount was due to the specification requirement that a "wearing coat" of screenings be left on the road.

The contractor is cautioned against careless examination of road specifications, for many engineers require the contractor to grade the subgrade exactly to grade and then put on enough stone to bring the finished macadam up to the established road grade. This causes the contractor to lose all stone that is driven into the subgrade by the roller, which in sand, or in soft wet clay, may amount to 2 ins. or more of loose stone.

Some specifications also foolishly require a ½-in. "wearing coat" of screenings to be left on the finished road, and this also amounts to a good many cubic yards of wasted material in a mile.

The roadmaker will do well to carry in mind the following data:
A bed 1 in. thick, 10 ft. wide and a mile long, contains 163 cu. yds.
A bed 6 ins. thick, 16 ft. wide and a mile long, contains 1,564 cu. yds.

Few rocks are soft enough to yield a sufficiently large percentage of screenings to bind the macadam; in which case screenings must be imported, unless the specifications permit the use of loam, sand, or clay.

Macadam roads are usually made 4 to 6 ins. thick after rolling, and 12 to 16 ft. wide. I have often urged the more common use of single track macadam roads, 8 ft. wide, with turnouts (16 ft. wide) located every few hundred feet apart.

Cost of Loading Stone From Cars Into Wagons.—A good workman, shoveling stone from a flat car into a wagon, will load 20 cu. yds. (loose measure) per 10-hr. day, giving a cost of 7½ cts. per cu. yd. when wages are $1.50.

Where the amount to be handled warrants the use of a derrick, and clamshell bucket, a much lower cost can be attained. Consult the section on Rock Excavation for details of cost of loading broken stone. (See page 197, etc.)

Cost of Loading Stone From Bins Into Wagons.—If the broken stone is to be hauled direct from the crusher, bins should always be erected to receive the broken stone. The bottom of the bin should have a slope of not less than 1 to 1, and should be lined with sheet iron. If the slope is flat, say 1½ to 1, a wagon cannot be loaded in much less than 7 mins., and then a potato-hook or hoe must be used to keep the stone moving. But, with a 1 to 1 slope, the stone runs freely, and a wagon can be loaded with 1½ cu. yds. in 2 mins. or less.

Usually one man operates the bin gates and assists the driver in trimming the load on the wagon. Hence the unit cost of loading from bins is the wages of the bin man divided by the total number of cubic yards crushed daily. If his wages are $1.50 and the crusher output is 65 cu. yds., the cost of loading from the bins is 2.3 cts. per cu. yd.

Cost of Hauling Stone in Wagons.—When wagons are loaded from cars, it is not economic to have more than 4 men shoveling into a wagon. These men will load a cubic yard of broken stone in about 6 or 7 mins., if working briskly. If a team (with driver) receives $3.50 per 10-hr. day, each minute of team time costs 0.6 ct.; hence the lost team time while loading amounts to about 4 cts. per cu. yd. If the loading is done from bins, the lost team time is about 1⅓ min. per cu. yd., or less than 1 ct. per cu. yd.

The lost team time at the dump is 5 mins. for a load of 1½ cu. yds., or more than 3 mins. per cu. yd., if slat-bottom dump wagons are used, costing nearly 2 cts. per cu. yd. for team time lost dumping. In dumping from a slat-bottom wagon, dump the load in 3 small piles, to reduce the labor of spreading.

Up-to-date contractors are now using bottom dump wagons extensively on roadwork. In dumping stone from such a wagon, fasten a chain around the body of the wagon so that the bottom doors can open only 6 ins. when the load is dumped, and keep the team traveling while dumping, so as to spread the load as much as possible. When such wagons are used, there is practically no lost team time dumping.

Special "spreader wagons" are frequently used, and, in that case also, there is practically no lost team time dumping the load.

It will be seen that the lost team constitutes a fixed cost per cu. yd., which may range from 1 ct. per cu. yd., where loading is done from bins and unloading from bottom dump wagons, to 7 cts. per cu. yd., where wagons are loaded from cars and where slat bottom wagons are used. For subsequent illustration, we shall assume 4 cts. per cu. yd. for lost team time, wages of team being $3.50 per 10-hr. day.

As 1½ cu. yds., or 1.9 tons, is a common load of broken stone hauled over earth roads, and as a common speed is 2½ miles per hr.,

or 220 ft. per min., the cost of hauling is 28 cts. per load per mile, or 19 cts. per cu. yd. per mile, measured one way from the point of loading to the point of dumping (wagon returning empty), team wages being $2.50 per 10-hr. day. To this must be added the fixed cost of lost team time, above given at 1 to 7 cts. per cu. yd.

If the earth roads are level and in good condition, a load of 2 cu. yds. may be hauled.

If the haul is over a good macadam road, 3 cu. yds., or 3.7 tons may be hauled, but it often happens that specifications foolishly prohibit any hauling over macadam before the rolling has been completed, in which case the contractor must usually begin construction at a point far from his stone supply and build the road back toward the stone supply, thus hauling over earth the entire distance, and doubling the cost of hauling.

In estimating the average length of haul on roadwork, bear in mind that the haul is never constant, and that at times the work will be too great for 5 teams, for example, but not enough to keep 6 teams fully busy. After estimating the cost by the above rules, for the actual average haul, I consider it fair to add about 15% to cover the added cost due to variable haul, and the added cost of team time due to delays at the crusher.

For discussion of the general subject of hauling, including traction engine hauling, see the last section of this book.

Cost of Spreading Stone By Hand.—When the stone is dumped in comparatively small piles on the subgrade, one man will spread 25 cu. yds. of the coarse broken stone in 10 hrs., at a cost of 6 cts. per cu. yd. when wages are $1.50. This is my own record (12 years ago) for several thousand yards of stone delivered in slat-bottom wagons. Subsequently I developed the method of machine spreading, described hereafter, which greatly reduced the cost.

The following records confirm my own, all being recorded in recent issues (1907 to 1909) of *Engineering-Contracting.*

Mr. Curtis Hill states that each man averaged 28 cu. yds. per day, in Missouri.

Mr. A. N. Johnson states that spreading 44,000 cu. yds. cost 8 cts. per cu. yd. He gives the wages on about half the jobs, indicating an average of about $2.00 a day for the whole work, which would mean that 25 cu. yds. were spread per man per day.

Mr. W. W. Crosby gives records for negro labor in Maryland, showing an average of 22 cu. yds. per man per day; wages were $1.00 for 10 hrs.

The foregoing show what may be accomplished with energetic workmen, but there are numerous instances where the cost of spreading has been three times as high. For example, Mr. John McNeal states that the average cost was 2½ cts. per sq. yd. for spreading stone by city day labor on 14,000 sq. yds., in Easton, Pa., the macadam being 6 ins. thick after rolling. This is equivalent to 15 cts. per cu. yd. of consolidated macadam, or 24 cts. per cu. yd. of loose stone; and, as wages were $2.00 per 10-hr. day, each man spread only a little more than 8 cu. yds. of loose stone per day.

However, a high cost of spreading is not of itself evidence of inefficiency. It frequently happens that engineers foolishly require all stone to be dumped upon platforms alongside the road, whence it is shoveled onto the road. In such cases, a man will not shovel and spread more than about 12 cu. yds. per day.

According to the common method of building a macadam road, the coarse stone is dumped in piles upon the subgrade, and spread with shovels and rakes. The screenings, however, are dumped in piles on the earth shoulders, and not on the subgrade. Then they are shoveled onto the coarser stone after it has been spread and well packed by rolling. This shoveling and spreading of the screenings costs much more per cubic yard of screenings than it costs to spread the coarse stone. A man will spread about 10 cu. yds. of screenings per 10-hr. day, making the cost 15 cts. per cu. yd. when wages are $1.50. Screenings cannot be spread with a leveler.

Cost of Spreading Stone With a Leveler or Grader.—Twelve years ago I hit upon the idea of using a grader for spreading broken stone. The "grader," or "leveler," as it has been recently called, was of the type shown in Fig. 1, excepting that the rooters or teeth

Fig. 1. Leveler for Spreading Stone.

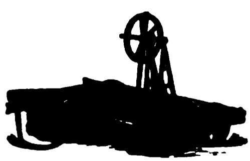


Fig. 2. Leveler for Spreading Stone.

were removed, as they are useful only in loosening hard earth on a subgrade that is being leveled. Fig. 2 shows another "leveler."

A "leveler" is a light machine having a steel blade about 5 ft. long, mounted in a frame, and capable of being raised or lowered. One team pulls the machine, and a man operates it, thus making the cost of operation $5.00 per 10-hr. day when team and driver are $3.50 and

operator $1.50. At these wages it costs only 1 ct. per cu. yd. to spread the coarse broken stone, for 50 cu. yds. can readily be spread per hour from small piles dumped on the subgrade. However, the spreading thus done by the "leveler" is not as true to surface as is necessary before rolling, so the layer of stone must be gone over by a man using a potato-hook for a rake. This final hand leveling adds another 1 ct. per cu. yd., making the total cost 2 cts. per cu. yd. for spreading the coarse stone. The screenings cannot be spread satisfactorily with the machine, but they constitute only a small percentage of the macadam.

I have known contractors who have attempted to improve on this method by using a large "road machine," but never with as satisfactory results. The four to six horses on a road machine add unnecessarily to the cost for this light work of spreading stone. Moreover, a road machine is not turned around so easily and quickly, and the turning around is apt to tear up the subgrade.

Due to the speed at which a leveler works, it is unnecessary to have a team constantly hitched to it. I prefer to unhitch a team from the sprinkler wagon at intervals during the day, for a few minutes at a time, and hitch it to the leveler.

For the best results at the lowest cost, dump the broken stone on the subgrade in as small piles as possible. Never dump the stone on the earth shoulders at the side of the road.

There are now several firms who make these "levelers," among them being: C. N. Carpenter Supply Co., Canton, Ohio; The Baker Mfg. Co., 725 Fisher Bldg., Chicago; The Ohio Road Mchy. Co., Oberlin, Ohio.

Cost of Rolling.—Based upon my own records of cost of maintaining and operating steam rollers (10-ton), which now extend over a period of 13 years, the following is the cost per day actually worked:

	Per day.
Engineman	$3.50
0.35 ton (700 lbs.) coal at $4 delivered	1.40
Oil, etc.	0.25
800 gals. (3¼ tons) water pumped and hauled 1 mile	1.00
Interest, 6% of $2,500 ÷ 100 days	1.50
Current repairs, and renewals, 5% of $2,500 ÷ 100 days	1.25
Depreciation (life 25 yrs.; sinking fund, 3% compound), 2.75% of $2,500 ÷ 100 days	0.70
Total	$9.60

It will be noted that I have assumed only 100 days per annum actually worked by a roller. In the northern half of America the road building season is not long enough to permit working much more than this; but it will sometimes happen that work is started early enough to enable at least 120 days to be worked, after deducting time lost on account of rains, etc.

Further data on depreciation and repairs of rollers will be found in subsequent pages.

Having established an approximate cost of $10 per day worked,

for operating and maintaining a roller, the next step is to determine the fair average yardage of macadam compacted per day. A roller can be counted upon to compact all the stone crushed by a 9x16-in. jaw crusher, where the crusher is working on hard quarry stone and averaging about 65 cu. yds. of loose broken stone and screenings per 10 hr. day. These 65 cu. yds. of loose stone will make 40 cu. yds. of compacted macadam, or 240 sq. yds. of macadam 6 ins. thick. Hence the cost of rolling is about 15 cts. per cu. yd. of loose stone (including screenings), or 25 cts. per cu. yd. of compacted macadam, or 4¼ cts. per sq. yd. of compacted macadam 6 ins. thick. This cost includes the ordinary steam rolling given to the subgrade before spreading the broken stone.

If the subgrade is very compact, or if new macadam is being laid on old macadam, a roller is capable of consolidating 50% more than the above given amount. On the ordinary soil, even after rolling it with a corrugated roller or a steam roller, the broken stone does not come to rest quickly under rolling, but waves under the roller for a long time. If the subgrade has been tamped with a rolling tamper, however, the average soil is so compacted that the broken stone is not driven into it, and the amount of steam rolling of the macadam is very greatly reduced.

One of my records shows that in 72 working days of 8 hrs. each, a 10-ton roller compacted 4,000 cu. yds. (24,000 sq. yds.) of 6-in. macadam, the subgrade being a compact gravelly soil. This is equivalent to 55 cu. yds. of compact macadam, or 330 sq. yds., per 8 hr. day, or nearly 7 cu. yds. or 42 sq. yds. per hr. This is a rapid rate, but is still far below the rate that I secured in resurfacing an old macadam that had been thoroughly broken up with picks, namely, 300 sq. yds. per hr., details of which are given on page 288.

In rolling 6-in. macadam at Hudson, N. Y., Mr. H. K. Bishop found that 60 cu. yds. of compacted macadam, or 360 sq. yds., was the average 8-hr. day's work of a 10-ton roller, which is equivalent to 45 sq. yds. per hr.

Mr. F. G. Cudworth states that in resurfacing an old macadam, 3.9 ins. of loose trap rock and 2.1 ins. of screenings were spread and rolled, the 10-ton roller averaging 472 sq. yds. per 10 hr. day.

Mr. W. C. Foster states that, in resurfacing an old macadam, a 12-ton roller averaged 314 sq. yds. of 6-in. macadam per 10 hr. day.

The three following records are taken from recent issues of *Engineering-Contracting.*

Mr. Curtis Hill states that in building a new 7-in. macadam road in Missouri, 65 cu. yds. of loose stone (the full output of the crusher) were rolled per day.

Mr. John McNeal states that in building new 6-in. macadam streets at Easton, Pa., a 12-ton roller averaged 200 sq. yds. per day, although on one street the average was 270 sq. yds. per day. The work was done by day labor, which accounts for the low average.

Mr. W. W. Crosby states that in building a new 6-in. macadam

road in Maryland, 300 sq. yds. were rolled per day of 10 hrs., less than 0.2 ton of coal being used by the roller.

If macadam is to be of thickness greater than 6 ins. (measured after rolling), it is usually built in two layers. It is evident that the top layer will require less rolling than the lower layer.

Cost of Sprinkling.—The amount of water used per cubic yard of macadam is exceedingly variable, depending largely upon the nearness of the water supply and the whim of the inspector. If the haul for the water is short, it is usually economy to use an abundance of water, for water washes the screenings into the voids of the coarse stone ("puddles"), and reduces the amount of rolling necessary to jar the screenings into the voids. I have used as low as 30 gals. per cu. yd. of compacted 6-in. macadam, which is equivalent to 5 gals. per sq. yd.; and I have used as high as 120 gals. per cu. yd., or 20 gals per sq. yd. of 6-in. macadam. It is usually safe to estimate on not more than 10 gals. per sq. yd. of 6-in. macadam, or 60 gals. per cu. yd. of compacted macadam.

The following records are taken from recent issues of *Engineering-Contracting.*

Mr. A. L. Valentine states that in building a 6-in. macadam road near Seattle, 9.3 gals. were used per sq. yd. Mr. W. W. Crosby states that 20 gals. per sq. yd. were used on a 6-in. macadam road in Maryland.

Mr. John McNeal states that, in one case, 16.8 gals. were used per sq. yd. of 6-in. macadam, and that, in another case, 16 gals. were used per sq. yd. of 10-in. macadam street.

In road building it is usually necessary to pump the water by hand, or with a small gasolene pump, from a creek, river or well. In 10 hrs. one man, with a hand pump, will raise 7,500 gals. of water to a height of 16 ft. into a tank from which it can be drawn off into the sprinkling wagon. Hence by working 3 hrs. a day, a man can furnish 2,400 gals. of water for 240 sq. yds. of 6-in. macadam. If wages are 15 cts. per hr., the cost of pumping to a height of 16 ft. is 1-50 ct. per gallon, or 1-5 ct. (one-fifth cent) per sq. yd. of 6-in. pavement where 10 gals. are used per sq. yd., or a trifle more than 1 ct. per cu. yd. of macadam.

On ordinary roads, unless there is a very steep pull from the creek or river bed, a sprinkling wagon holding 450 gals. (or 1.9 tons) of water can readily be hauled by a team. The team time required to load the sprinkler from a tank and discharge its contents on the road is ordinarily about 20 mins., costing 12 cts. for the 450 gals. when team is $3.50 per 10-hr. day. With a traveling speed of 2½ miles per hr., the cost of hauling is 28 cts. per tank (450 gals.) per mile of haul from water supply to point of delivery.

Hence, to a fixed cost of 12 cts. per tank (for team item loading and discharging the water), add 28 cts. per tank per mile of haul.

With a haul of 1 mile the cost is, therefore, 40 cts. per tank of 450 gals., or less than 1-10 ct. (one-tenth cent) per gallon. If 10 gals. are used per sq. yd. of 6-in. macadam, the cost of hauling

water the first mile is, therefore, 1 ct. per sq. yd., or 6 cts. per cu. yd. of compacted macadam; and each subsequent mile costs 4 cts. per cu. yd. of macadam.

It generally happens, however, that when the haul is a mile, or less, a sprinkling wagon is kept going continuously, regardless of the amount of water used. In that case, if wages of team and driver are $3.50 per 10-hr. day, and interest, depreciation and repairs of the sprinkling wagon are $0.50 per day, the daily cost of $4.00 must be divided by the amount of macadam compacted by the roller, or 40 cu. yds., making a cost of 10 cts. per cu. yd., or 1.7 cts. per sq. yd. of 6-in. macadam, regardless of how short the haul is.

In California, where the hauls for water are apt to be long, it is not unusual to see tank wagons holding 900 gals. or more, hauled by six horses. See page 322.

Summary of Cost of Macadam.—Based upon the foregoing rates of wages, etc., the following summary, Table I, is given:

TABLE I.—COST OF MACADAM.

Item.		Per cu. yd.	Per sq. yd. (6-in.).	Per ton (2,000 lbs.)
1	1.3 cu. yds. (1.62 tons) coarse stone f. o. b. cars at $0.75	$0.975	$0.163	$0.488
2	0.3 cu. yds. (0.38 tons) screenings, f. o. b. cars at $0.75	0.225	0.037	0.112
3	2 tons (1.6 cu. yds.) freight at $0.50	1.000	0.167	0.500
4	1.6 cu. yds. loaded into wagons at $0.08	0.108	0.018	0.054
5	1.6 cu. yds. lost team time loading at $0.04	0.064	0.011	0.032
6	1.6 cu. yds. hauled (1 mile) at $0.20	0.320	0.053	0.160
7	1.3 cu. yds. spread by hand at $0.06	0.078	0.013	0.039
8	0.3 cu. yds. spread by hand at $0.15	0.045	0.008	0.022
9	Rolling, $10 ÷ 40 cu. yds. macadam	0.250	0.042	0.125
10	Sprinkling, $4 ÷ 40 cu. yds. macadam	0.100	0.017	0.050
11	Foreman, ½ of $4.00 ÷ 40 cu. yds. macadam	0.050	0.008	0.025
12	Night watchman ($1.50), water boy ($0.75), and ½ of timekeeper (½ of $2.50); $3.50 ÷ 40 cu. yds.	0.088	0.015	0.044
13	General supervision, office expense, insurance, etc., at 8% of items 4 to 12 inclusive	0.112	0.017	0.056
	Grand total	$3.415	$0.569	$1.707

The cost per cu. yd. relates to a cubic yard of macadam packed in place, and not per cu. yd. of loose stone.

The cost per sq. yd. is for macadam 6 ins. thick after rolling, and is, therefore, exactly one-sixth of the cost per cu. yd.

The cost per ton is for a ton of 2,000 lbs. of stone having a specific gravity of 2.7, weighing 4,546 lbs. per cu. yd. solid (or 2,500 lbs. per cu. yd. loose broken stone having 45% voids) and assuming that the completed macadam weighs 4,000 lbs. (2 tons) per cu. yd. of completed macadam, which is equivalent to a macadam having only

a little more than 10% voids after rolling and binding. Codrington states, in the Encyclopedia Brittanica, that a piece of old macadam contained only 5% voids, as determined by careful weighing.

In considering each item, refer to the previous discussion.

If the stone is quarried near the road, item 3 (freight) will not exist; and item 4 (loading wagons) will be reduced to 1 ct. per cu. yd. of macadam; also item 5 (lost team time) will be reduced.

If the haul is 2 miles, item 6 will be exactly doubled; on the other hand, if the hauling can be done over a macadam road, this cost per mile can be cut in two, and it can be still further reduced if a traction engine is used.

If the coarse stone is spread with a "leveler," as it always should be, item 7 (spreading) will be exactly one-third as much as given; but item 8 will not be affected.

If the subgrade is naturally hard, or has been compacted with a rolling tamper having projected teeth or tampers, item 9 (rolling) may be reduced 30% or more.

If the haul of water for sprinkling is less than a mile, or if the sprinkler is not kept constantly busy, item 10 can be materially reduced.

Item 11 (foreman) is given on the basis of half the foreman's time being charged to the macadam, the other half being charged to grading; and the same being true of the timekeeper's time in item 12.

Item 13 (general supervision, etc.) is rated at 8% of all costs, except the cost of broken stone delivered on cars, for it is here assumed that the stone is purchased.

If wages of laborers and teams are greater than $1.50 and $3.50 per 10-hr. day, the above costs should be increased in direct ratio the increased wage.

Estimating the Cost of Macadam, New York State.*—For estimating a fair bidding price on the macadam used in New York State road construction, Mr. Henry A. Van Alstyne, has prepared the following data:

The actual cost of the crushed stone in bins is estimated at 85 cts. per cu. yd., measured loose. The cost of hauling this stone from the bins to the road is estimated at 35 cts. per cu. yd. (loose measuse) per mile of haul. The cost of spreading, rolling and sprinkling the broken stone is estimated at 30 cts. per cu. yd. of loose measure.

It is estimated that it takes 1⅓ cu. yd. of stone to make 1 cu. yd. of stone compacted under the roller; and that it takes ⅓ cu. yd. of screenings to bind this stone. Hence in estimating the cost of a cubic yard of loose broken stone we have:

	Per cu. yd.
Crushed stone in bins	$0.85
Hauling, 1¾ miles at $0.35	0.60
Spreading, rolling, etc.	0.30
Total (loose measure)	$1.75

*Engineering-Contracting, Aug. 1, 1906.

Based upon this method we have the following table of the cost of broken stone or screenings placed in the road:

Haul, miles.	Cost per cu. yd. (loose).
1¾	$1.75
2	1.85
2¼	1.95
2½	2.05
2¾	2.20
3	2.30
3¼	2.40
3½	2.50
3¾	2.60
4	2.70
4¼	2.80
4½	2.90
4¾	3.00
5	3.10

Then the cost of a cubic yard of solid macadam is estimated as follows, assuming a haul of 1¾ miles:

	Per cu. yd. macadam.
1.33 cu. yds. broken stone at $1.75	$2.33
0.5 cu. yds. screenings at $1.75	0.88
Total	$3.21
Add 20% for profit	0.64
Contract price	$3.85

This is practically $3.90, and it is so entered in the following table:

Contract Price for Macadam with Screenings Binder.

Haul, miles.	Price per cu. yd.	Price per sq. yd. per inch of thickness. Cts.
1¾	$3.90	10.8
2	4.10	11.4
2¼	4.30	12.0
2½	4.50	12.5
2¾	4.70	13.1
3	4.90	13.6
3¼	5.10	14.1
3½	5.25	14.6
3¾	5.45	15.1
4	5.65	15.7
4¼	5.85	16.2
4½	6.05	16.8
4¾	6.25	17.3
5	6.45	17.9

The above is based upon the use of stone screenings for the binder, as required for the middle and top course of macadam, which are usually 3 ins. thick (2 ins. middle course and 1 in. top course). But for the bottom course, which is usually 3 ins. thick, the specifications permit the use of sand as a binder instead of screenings. This sand is estimated at $1 per cu. yd., loose measure, including loading, hauling, spreading, profit, etc., or 83 cts. per cu. yd. without

the 20% profit. Hence, for a haul of 1¾ miles, we have the following for the bottom course:

	Per cu. yd. macadam.
1.33 cu. yds. broken stone at $1.75	$2.33
0.5 cu. yds. sand filler at $0.83	0.42
Total	$2.75
Add 20% profit	0.55
Contract price	$3.30

Based upon this method of calculation we have the following as the cost of the bottom course for different lengths of haul:

Contract Price for Macadam With Sand Binder.

Haul, Miles.	Price per cu. yd.	Price per sq. yd. per inch of thickness. Cts.
1¾	$3.35	9.3
2	3.50	9.7
2¼	3.65	10.1
2½	3.80	10.5
2¾	3.95	10.9
3	4.10	11.4
3¼	4.20	11.6
3½	4.35	12.0
3¾	4.50	12.5
4	4.65	12.9
4¼	4.80	13.3
4½	4.95	13.8
4¾	5.05	14.0
5	5.20	14.4

The foregoing data are based upon the assumption that loose broken stone costs 85 cts. per cu. yd. in the crusher bins. If the stone is delivered on cars the cost often is higher, and to this cost must also be added 15 cts. per cu. yd. of loose stone for shoveling the stone from the cars into wagons.

The rates of wages paid by contractors in New York State roadwork are usually $1.50 per 8-hour day for common laborers, and $4 to $4.50 per day for team and driver.

Prices Allowed for Extra Work on New York State Roads.*—A good many of our readers will be interested in two features of the latest specifications for macadam and gravel roads built by the State of New York. One feature is the method adopted to prevent unbalancing of bids, and the other feature is the specifying of unit prices which the contractor must accept for extra work.

The State Engineer's estimate of the quantities of every kind of work specified is given in detail, but the contractor is required to bid a lump sum for the road complete. This, of course, prevents unbalancing of bids. Then, to avoid disputes or law suits in case any or all of the quantities are increased or diminished the following clause is inserted in the contract:

"And in consideration of the acceptance of the foregoing proposal we hereby agree to accept the following named unit prices

**Engineering-Contracting,* Aug. 1, 1906.

(Table II) for any increase or deduction which may be made by the State Engineer for changes made under the provisions of the specifications for said improvement."

It should be added that for ordinary conditions the State Engineer estimates a minimum price of macadam with a sand binder (bottom course) at $3.25 per cu. yd.; and for the other courses (middle and top), $3.90 per cu. yd. including binder.

Very complete specifications for this road work have been prepared by Henry A. Van Alstyne, State Engineer, Albany, N. Y. Engineers engaged in road construction will find much valuable information embodied in these specifications.

Macadam Road Prices in Massachusetts.*—Some interesting data in the construction of macadam roads in Massachusetts are given in a recent bulletin prepared by Austin B. Fletcher, secretary Massachusetts Highway Commission, and issued by the U. S. Office of Public Roads. According to this the average costs (by contract) to the state of Massachusetts of broken stone in place on state highways constructed in 1906 were as follows: For a road made of imported stone (trap rock), 6 in. deep at center and 4 in. deep at sides, the cost per ton in place was $1.956; the cost per square yard in place was $0.6245 and the cost per mile was $5,496. One ton of stone made 3.13 sq. yds. of macadam. For a road made of imported stone (trap rock) 4 ins. deep throughout, the cost per ton in place was $2.025; the cost per square yard in place was $0.5393 and the cost per mile was $4,746. One ton of stone made 3.76 sq. yds. of macadam. For a road made of local stone 6 ins. deep at center and 4 ins. deep at sides, the cost per ton in place was $1.396; the cost per square yard in place was $0.4201 and the cost per mile was $3.696. One ton of stone made 3.32 sq. yds. of macadam. For a road made of local stone 4 ins. deep throughout, the cost per ton in place was $1.583; the cost per square yard in place was $0.3931 and the cost per mile was $3,459. One ton of broken stone made 4.03 sq. yds. of macadam. The above costs per mile are equated on the basis of a road 15 ft. wide. The average contract prices for the several construction items exclusive of macadam were as follows:

Excavation per cu. yd.	$0.435
Borrow per cu. yd.	0.562
Ledge excavation per cu. yd.	1.78
Cement concrete masonry, cu. yd.	8.85
Shaping road for broken stone per sq. yd.	0.028
Vitrified 18-in. clay pipe, in place, per lin. ft.	1.57
Vitrified 12-in. clay pipe, in place, per lin. ft.	0.766
Vitrified 10-in. clay pipe, in place, per lin. ft.	0.643
Vitrified 8-in. clay pipe, in place, per lin. ft.	0.570
Iron water pipe, 12 in., in place, per lin. ft.	2.20
Iron water pipe, 18 in., in place, per lin. ft.	3.75
Stone filling for V drains, in place, per cu. yd.	0.827
Guard rail, in place, per lin. ft.	0.277
Catch basins, in place (including catch basin frames and grates), each	35.74
Setting stone bounds	1.85

The price for cement concrete masonry does not include the ce-

*Engineering-Contracting, Oct. 16, 1907.

TABLE II.—PRICES FOR ROAD WORK.

The following are unit prices for the items named, in place, complete:

Excavation of earth, or embankment rolled in place, per cu. yd.	$ 0.40
Excavation of rock, per cu. yd.	1.25
Second-class Portland cement concrete, in place complete (1 : 2½ : 5), per cu. yd.	8.00
Third-class Portland cement concrete, or third-class masonry, in Portland cement mortar, in place complete (1 : 3 : 6), per cu. yd.	6.00
Third-class masonry laid dry, in place complete (rubble), per cu. yd.	3.50
Pointing old masonry, per sq. yd.	0.20
Rip-rap, in place complete, per cu. yd.	1.50
Telford base, in place complete (6-in. to 8-in. thick), per sq. yd.	0.75
Stone paving, in place complete (8-in. thick), per sq. yd.	0.75
Cobble gutters, in place complete, per sq. yd.	0.50
6-in. stone flagging, in place complete (for covering box culverts), per sq. ft.	0.30
Expanded metal, 6-in. mesh (or 3—16-in.) gauge, in place complete, per sq. ft.	0.10
Guard rail, in place complete (posts 7-ft. long, 8 e to e), per lin. ft.	0.20
Rustic guard rail, in place complete, per lin. ft.	0.15
Bridge rail, in place complete, per lin. ft.	0.50
1¼-in. pipe rail, in place complete (for masonry bridges), per lin. ft.	1.00
12-in. cast iron pipe, laid in place complete, per lin. ft.	2.50
18-in. cast iron pipe, laid in place complete, per lin. ft.	3.50
6-in. vitrified pipe, laid in place complete, per lin. ft.	0.30
12-in. vitrified pipe, laid in place complete, per lin. ft.	0.60
18-in. vitrified pipe, laid in place complete, per lin. ft.	1.10
24-in. vitrified pipe, laid in place complete, per lin ft.	2.00
30-in. vitrified pipe, laid in place complete, per lin. ft.	3.75
Relaying old pipe found in road, per lin. ft.	0.15
Steel beams, channels and structural shapes, spikes and nails and cast iron, per lb.	0.05
Oak timber and plank, in place complete, per 1,000 ft. B. M.	40.00
Hemlock timber and plank, in place complete, per 1,000 ft. B. M.	30.00
Yellow pine timber and plank, in place complete, per 1,000 ft. B. M.	40.00
Guide boards, each	6.00
Road signs, each	4.00

Prices for the Following Items to Be Inserted by Bidder.

Broken stone macadam of the kind prescribed in these specifications, for bottom course, including filler, and rolled in place complete, per cu. yd.	——
Broken stone macadam of the kind prescribed in these specifications, for middle course, including binder, and rolled in place complete, per cu. yd.	——
Broken stone macadam of the kind prescribed in these specifications, for top course, including binder, and rolled in place complete, per cu. yd.	——
¾-in. broken stone of the kind prescribed in these specifications, in piles, loose measurement, per cu. yd.	——
Gravel or shale, rolled in place, per cu. yd.	——

ment or the steel reinforcement, which may be estimated at about $3 additional. The average wages per 9-hour day for part of 1906 and for an 8-hour day for the remainder of the year were as follows:

Ordinary labor	$1.75 to $2.00
Crusher and roller engineers	3.00 to 3.50
Foreman	3.00 to 5.00
1-horse wagon and driver	3.00 to 4.00
2-horse wagon and driver	4.50 to 5.50

Contract Prices for Road Work in Massachusetts.*—The following averages of contract prices on state road work during 1907 have been taken from the 15th annual report of the Massachusetts Highway Commission. The prices are the averages for 64 contracts:

Excavation, all kinds, per cu. yd.	$0.52
Borrow, per cu. yd.	0.64
Ledge rock excavation, per cu. yd.	1.95
Concrete masonry, per cu. yd.	9.84
Shaping, per sq. yd.	0.03
Broken stone, local, per ton, in place	1.64
Broken stone, traprock, per ton, in place	2.20
Pipe culverts, per lin. ft.:	
12-in. vitrified clay, in place	0.80
18-in. vitrified clay, in place	1.66
12-in iron, in place	2.34
18-in. iron, in place	3.57
Fencing, per lin. ft.	0.30

Ledge excavation covers only such ledge rock as requires blasting for its removal, and boulders of ½ cu. yd. or more in volume. Concrete masonry is composed of 1 part Portland cement, 2 parts sand and 5 parts broken stone or gravel. For the pipe culverts nothing but selected fine material, free from large stone, shall be placed under and about the pipe, and all material under and about the pipe shall be tamped in place by a thin tamping bar. Fencing consists of chestnut or cedar posts not less than 6 ins. in diameter spaced 8 ft. apart and set 3 ft. in the ground and 3½ ft. above. The top rail is 4 ins. square and the side rail of 2x6-in. spruce.

Wages in Massachusetts in 1907, per 8-hour day, were about as follows: Common labor, $1.75 to $2.25; team with driver, $4.50 to $5.

Per Cent of Engineering for Road Construction.†—During 1905 and 1906 there were built in New Castle County, Delaware, 7.48 miles of macadam road and 2.9 miles of gravel road. The per cent of engineering expenses on these roads varied from 2 per cent to 3.7 per cent, the average being 2.2 per cent.

In Madison County, Tennessee, 24¼ miles of macadam roads were built at a cost of $115,681.71. The cost of engineering, superintendence and surveys was $7,016.35, or about 6 per cent of the total amount expended.

In Pennsylvania the average cost of inspection on roads built for the State Highway Department has been 3 per cent of the cost

*Engineering-Contracting, Aug. 26, 1908.

†Engineering-Contracting, Sept. 23, 1908, and Apr. 28, 1909.

of the road and the average of engineering expenses has been 2 per cent, or a total of 5%.

In New Jersey, during 1908, a total of 146 miles macadam and gravel roads were built. Engineering and inspection averaged about 5.7%, of which 3.2% was for engineering and 2.5% for supervisor's salary, the supervisor being appointed by each county to oversee and direct the work.

Cost of Macadam Roads, New Jersey.—The following is a very brief summary of a table of quantities and bidding prices for 47 different macadam, gravel and Telford roads, which was given in *Engineering-Contracting*, April 28, 1909. There were 146 miles of these New Jersey state roads built in 1908, the following being about the average cost of a macadam road 6 ins. thick (after rolling) and 14 ft. wide:

	Per mile.
8,210 sq. yds. macadam at 65 cts.	$5,337
4,100 cu. yds. earth excav. at 34 cts.	1,394
Engineering (3.2%)	214
Supervisor's salary (2.5%)	167
Total	$7,112

About as many roads were built 8 ins. thick as 6 ins., at an added cost of about 20 cts. per sq. yd. for the 8-in. roads.

Cost of a Limestone Macadam Road, Buffalo, N. Y.—The following data apply to a limestone macadam road 6 ins. thick and 12 ft. wide, built by contract near Buffalo, N. Y., in 1898. The earth was a tough clay and ditches nearly 3 ft. deep were dug along both sides of the road. The cost of digging the ditches was nearly half the total cost of grading. The following was the cost of one mile of grading, including ditching and surfacing, in comparatively level country, the amount of excavation being about 4,600 cu. yds. (the graded road was 22 ft. wide between ditches):

Labor at $1.50 per 10-hr. day	$ 670
Teams at $3.50 per 10-hr. day	226
Foreman at $2.50 per 10-hr. day	97
Waterboy at $1.00 per 10-hr. day	17
Total per mile	$1,010

This is equivalent to about 22 cts. per cu. yd.

There were stretches of this road where ditches already existed, and the only grading required was to plow up the old surface, shape the trench to receive the macadam, and make the earth shoulders 5 ft. wide on each side of the macadam. Such stretches of grading cost $320 a mile.

The macadam was 6 ins. thick after rolling and 12 ft. wide. It was laid in two courses: (1) a foundation course of 1¼ to 2½-in. limestone, 4 ins. thick after rolling; and (2) a top course of ¾ to 1¼-in. limestone, 2 ins. thick after rolling. Both courses were bound with limestone screenings. As an average of 3¼ miles of road, it was found that loose stone spread to a depth of 6 ins. was rolled down with a 10-ton roller to an apparent thickness of 4 ins., but without doubt about 1 in. of stone was pushed into the subgrade and lost so far as the final measurement was con-

cerned. It therefore took 1⅓ cu. yds. of loose (1¼ to 2½-in.) stone (measured in cars or wagons) to make 1 cu. yd. of rolled foundation course. For the top course it took a thickness of 2.8 ins. of loose (¾ to 1¼-in.) stone to give the required 2-in. thickness after rolling. This indicates also a further pushing of the foundation stone into the clay below, for all measurements of thickness were made with a level, and not by digging holes through the finished macadam. The average of these two courses was 1.46 cu. yds. of loose stone (not including screenings) to make 1 cu. yd. of rolled stone, but it took a trifle over ⅓ cu. yd. of limestone screenings (from size of dust up to ½-in.) to bind each cubic yard of rolled macadam. We have, therefore:

Loose stone	1.46 cu. yds.
Screenings	0.34 cu. yd.
Total	1.80 cu. yds.

This means that it required 1.8 cu. yds. of screenings and loose stone (measured in wagons) to make 1 cu. yd. of rolled macadam. The cost of each cubic yard of macadam was as follows:

Stone and screenings, f. o. b., 1.8 cu. yds., at $0.70	$1.26
Freight, 25 cts. ton, 1.8 cu. yds., at $0.28	0.50
Unloading cars into wagons, 1.8 cu. yds., at $0.11	0.20
Hauling ¾ mile, 1.8 cu. yds., at $0.28	0.50
Spreading, 1.8 cu. yds., at $0.08	0.14
Sprinkling	0.19
Rolling, including rolling subgrade	0.24
Total per cu. yd. of macadam	$3.03

Laborers received $1.50, and teams (with drivers) $3.50 per 10-hr. day.

Cost of a Sandstone and Trap Macadam, Rochester, N. Y.—Near Rochester, N. Y., a macadam road 16 ft. wide and 6 ins. thick was built by contract, on a sandy soil. The bottom 4 ins. of the macadam were of sandstone bound with limestone screenings. The top 2 ins. were of trap rock bound with limestone screenings. The sandstone was fieldstone obtained mostly from old stone fences near the road. Wages of common laborers were 15 cts. an hour; teams, 35 cts.

The cost of sandstone crushed and delivered on the road was as follows per cubic yard measured in the wagons:

	Cu. yd.
Paid farmers for fences	$0.10
Loading, hauling ½ mile, and crushing	0.80
Hauling 1 mile and spreading	0.35
Total	$1.25

The limestone screenings, used as a binder, were imported on canal boats, and delivered on the road cost as follows per cubic yard measured in the wagons:

	Cu. yd.
Screenings delivered on boats	$1.50
Unloading into wagons with derrick	0.25
Hauling 2 miles	0.30
Spreading on road	0.15
Total	$2.25

The cost of the trap rock was the same as for the limestone screenings. The cost of the 4-in. sandstone base was as follows:

	Cu. yd.
1.4 cu. yds. sandstone, at $1.25	$1.75
½ cu. yd. limestone screenings, at $2.25	0.75
Rolling and sprinkling	0.08
Total (measured in place)	$2.58

The cost of the 2-in. trap wearing coat was as follows:

1.4 cu. yds. trap, at $2.25	$3.15
½ cu. yd. screenings, at $2.25	0.75
Rolling and sprinkling	0.52
Total (measured in place)	$4.42

The 10-ton roller pushed much of the stone into the sandy subgrade, which accounts in part for the fact that it took 1.4 cu. yds. of loose stone to make 1 cu. yd. of rolled macadam. No very accurate record was kept of the amount of screenings used, but the amount stated is not far from correct. It will be noted that rolling the 4-in. lower course cost only 8 cts. per cu. yd. as compared with 52 cts. per cu. yd. for the 2-in. top course. This is due to the fact that the lower course was hastily rolled. Strictly speaking these two courses should not be treated separately in discussing the cost of rolling. The cost of rolling and sprinkling the two courses was 24 cts. per cu. yd.

Cost of Experimental Macadam Roads, Illinois.*—Mr. A. N. Johnson gives the following regarding 12 experimental macadam roads (13.76 miles) built in Illinois in 1907 and 1908. The work was done by day labor. Each road was made 12 ft. wide, and two layers of loose broken stone were laid to an aggregate depth of about 10 ins., which would be equivalent to a little more than 6 ins. of compacted macadam. Limestone, weighing about 2,500 lbs. per cu. yd., was used, costing about $1.25 per cu. yd. on cars at the destination. The cost of 44,000 cu. yds. of loose broken stone was as follows per cubic yard (loose measure):

Labor.	Per cu. yd. (loose).	Per cent.
Unloading stone from car	$0.10	10.1
Hauling stone	0.32	34.0
Spreading stone	0.08	8.5
Rolling and sprinkling	0.11	11.5
Total labor on stone	$0.61	64.1
Excavation of earth	0.12	12.4
Shaping roadbed	0.08	8.3
Trimming shoulders	0.05	5.3
Supt., watchman and incidentals	0.09	9.9
Total labor	$0.95	100.0
Stone, f. o. b. cars, say	1.25	
Grand total	$2.20	

It is not stated whether interest and depreciation of steam roller are included, but apparently not. Average rates of wages are not given for these 44,000 cu. yds., but wages on 8 different jobs in

*Engineering-Contracting, Nov. 18, 1908.

1908 (involving 25,000 cu. yds. of stone) are given, and average $2.10 per day; team (with driver) averaged $4.20.

The 1¼-in. size stone was used for the bottom layer, and the 3-in. stone, bonded with screenings, was used for the top layer, reversing the usual practice.

Irregular shipments of stone and bad weather caused delays that added considerably to the cost.

If the above given costs per cu. yd. of stone (loose measure) be multiplied by 0.3, the approximate cost per sq. yd. will be obtained.

The shaping of roadbed averaged 2.4 cts. per sq. yd. of macadam, although on one job it cost only 1.8 cts. although the wages were $2.50 a day.

The trimming of shoulders cost 1.5 cts. per sq. yd. of macadam.

The total cost per mile of macadam road, 12 ft. wide, 10 ins. thick before compacting (about 5 ins. afterward), was about $5,900, the haul of stone averaging 1 to 1½ miles.

Data on Depreciation and Repairs of Steam Road Rollers.*— Steam road rollers were first built in England about 1865, and it is to England that we naturally look for the most complete records of the cost of repairs and the life of these machines.

The English author, Thomas Aitken, has kept careful records for a period of more than 20 years, and his data are especially valuable not only to English but to American road builders.

Aitken gives the following table of first cost of English rollers:

15-ton roller, single cylinder	$2,300
12-ton roller, single cylinder	2,000
10-ton roller, single cylinder	1,875

Aitken puts the life of a roller at not less than 25 years. He estimates 8,000 tons of stone consolidated by a 15-ton roller each year.

Aitken gives the following cost of repairs on a 15-ton roller, which he regards as typical:

"Up to the fourteenth year the repairs were comparatively trifling, with the exception of a pair of new driving wheels and repairing the fire-box and tubes, etc. These latter, and including sundry repairs, amounted, on an average, to $55 per annum. It was then found necessary to have a new fire-box and general overhaul of all the working parts. This cost $850, and the engine should, it is anticipated, be capable, with ordinary repairs, to run for a period equal to a life of 25 years at least."

Aitken puts the total cost of renewals and repairs of a $2,300 roller at $105 a year during a life of 25 years, which is nearly 5 per cent of the first cost each year. To this must be added a percentage to cover depreciation, that is to provide a sinking fund sufficient to buy a new roller at the end of 25 years. If such a sinking fund draws 3 per cent compound interest, it requires that about 2.75

Engineering-Contracting, April 7, 1909.

per cent of the first cost of the roller be set aside annually to amount to the full first cost of the roller in 25 years. This 2.75 per cent depreciation fund allowance if added to the 5 per cent for repairs and renewals, gives a total of nearly 8 per cent per annum.

Aitken says that this is equivalent to 83 cts. per working day. Since 8 per cent of $2,300 is $184, if we divide the $184 by $0.83, we find that Aitken apparently figures on 221 working days in the year, which is almost double the number of days commonly worked by a roller in the northern part of the United States. (See *Engineering-Contracting*, May 23, 1906, July 3, 1907 (p. 7), June 10, 1908 (p. 358), for data as to the number of days worked in Massachusetts, and the cost of roller repairs.) Aitkin says that his estimate relates to a roller used in macadam repair work, "practically in steam all the year, except when under repairs or stopped by frost during winter months."

There is a seeming discrepancy in his figures, for he rates a 15-ton roller as capable of compacting at least 64 tons of macadam per day of 9 hours, if not interfered with by traffic. Elsewhere he estimates the "useful effect of one roller at 8,000 tons of macadam per annum," from which it would appear that less than 150 full days would be worked, or that delays due to traffic would cause a serious loss of time.

The writer's experience is that 75 tons of macadam can be compacted per 10-hour day, and that a contractor can usually count on about 100 to 110 days' actual work, which gives a total of some 8,000 tons (including screenings) compacted each season by a 10-ton roller.

Regarding the repairing of the driving wheels, Aitken says:

"The renewal of the driving and front wheels, especially the former, is an expensive item, and what was considered at one time impracticable can now be carried out, that is, plating the worn-out rims. This results in considerable saving, and the wear of the metal forming the rims is considerably less than in the original wheels. It should be stated, however, that the wheels for renewal of rims should not be worn too thin, as, in such cases, the renewal is not so satisfactory. The process is to fit steel plates on the old rims and rivet the two together, and, apart from a few of these becoming loose, which can be remedied by counter-sunk bolts, the arrangement is in every way successful. The gripe or 'bite' of these steel-plated wheels is as good as that of the original cast-iron ones, and the wear is much more uniform."

Aitken goes on to state that the wear of these steel-plated rims is 0.02 in. for every 1,000 tons of macadam consolidated, and that the cost of repairing the driving wheels by this method is $200 as against $250 for a complete set of new wheels, and that "experience shows that the life of those renewed with steel plates is nearly doubled."

There seems to be enough merit in this method of repairing the driving wheels to warrant the manufacturer's making them with removable steel plate rims in the first place. If the plates were of

manganese steel the life would probably be three to four times as long as when made of ordinary steel.

Aitken states the cast-iron driving wheels of a 15-ton roller lasted 7 years, during which time they consolidated 60,000 tons of macadam.

Cost of Road Roller Repairs in Massachusetts During 1908.*—The Massachusetts Highway Commission had under its control 18 steam road rollers. The rollers were used 1,126¼ days on town work, in 32 different towns. They were also used 557½ days on state highway repair work, on 65 different roads; 290 days by towns contracting for the building of state roads, including the small town roads; 162 days by private contractors on state highway contracts, and one roller was used eight days at the State Farm at Bridgewater. The total number of days' work during the year was 2,144—an average of 119 days for each roller. The total cost of such maintenance for the year was $2,046. Of this amount $1,000 was paid for practically rebuilding one of the rollers which had been in active use since 1896; and $1,046 was expended for the ordinary repairs. Including the expense of supervision and inspection of the rollers, the average cost of such ordinary repairs during 1908 was 90.8 cts. per day for each roller in use. A comparison of the above figures with those of the years 1906 and 1907 is given below:

	1906.	1907.	1908.
Number of rollers	16	16	18
Total days worked	1,719½	1,808	2,144
Av. days per roller	107½	113	119
Av. cost ordinary repairs per roller day	$0.98½	$0.99½	$0.90 4/5

In *Engineering-Contracting*, May 23, 1906, it is stated the Massachusetts Highway Commission had 16 rollers during 1905, that they averaged 90.3 days worked per roller, and that the cost of ordinary repairs was $1.12 per roller per day worked.

Cost of Scarifying Macadam By Hand.—Mr. Thomas Aitken is authority for the following English data:

When a macadam surface is to be picked, or scarified, by hand, soak the crust with water to soften it, unless it is the intention to screen the old materials. The depth to which the macadam is loosened by picks is usually about 2½ ins. One man will loosen at the following rate per day:

	Sq. yds.
Soft macadam	33
Hard macadam	20
Very hard (steam rolled) macadam	12 to 15

Cost of Scarifying With a Machine.—A scarifier is a heavy harrow for ripping up old macadam preparatory to resurfacing it. See Fig. 3.

A scarifier is pulled by a steam roller, and it usually requires two men to operate the scarifier. According to Thomas Aitken, a scarifier with 3 teeth, spaced 6 ins. apart, will break up old macadam

**Engineering-Contracting*, May 5, 1909.

to a depth of 4 ins. at the rate of 3,000 sq. yds. per 10-hr. day, if not interrupted by traffic. He gives one record of 650 cu. yds. per hr., scarified to a depth of 3 ins., using a 15-ton roller to pull it. But, allowing for interruptions from traffic that ordinarily occur on a country road, he gives 1,500 to 2,000 sq. yds. per 10-hr. day.

He states that each set of teeth will scarify only 150 sq. yds. before requiring sharpening, and that it costs 15 to 30 cts. to sharpen the set of 3 teeth, at which rate it costs 0.1 to 0.2 ct. per sq. yd. for sharpening the teeth. This would give a cost of $3 to $6 per day for sharpening teeth where 3,000 sq. yds. are scarified daily.

The following paragraph gives some American data.

Cost of Scarifying Macadam, Rhode Island.*—In breaking up the crust of an old macadam road preparatory to mixing it with tar or asphaltic oil, a scarifier drawn by a steam roller is cheaper than the use of "picks" in the rear wheels of the roller.

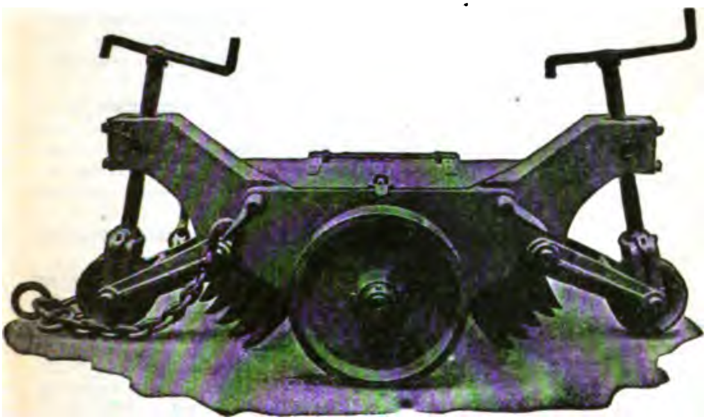


Fig. 3. Scarifier.

This is well illustrated by the following costs of scarifying which have been furnished to us by Mr. Arthur H. Blanchard, assistant engineer of the State Board of Public Roads, Providence, R. I.

An old macadam road at Tiverton, R. I., was scarified to a depth of 3 or 4 ins. at a cost of 0.7 ct. per sq. yd. The steam roller and scarifier were rented. The price paid for the steam roller, including fuel and wages of engineman, was $10 per day of 10 hours, which is a reasonable price. The price paid for the use of the scarifier was $5 a day, which is reasonable when due allowance is made for the cost of sharpening its teeth. Two laborers, at $2.50 each per

*Engineering-Contracting, Oct. 28, 1908.

10-hour day, operated the scarifier. Therefore the daily cost was as follows:

	Per day.
Roller, including engineman	$10.00
Scarifier	5.00
2 laborers, at $2.50	5.00
Total	$20.00

The average 10-hr. day's work was 2,788 sq. yds. scarified, hence the cost per square yard was:

	Cts., per sq. yd.
Roller, including engineman	$0.36
Scarifier	0.18
Laborers	0.18
Total	$0.72

It may be well to add that the practice of using "picks" in the rear wheels of a steam roller is not to be commended, for the resulting shocks to the whole machine, and particularly to the boiler, are injurious. Boiler tubes quickly become loosened and leak badly under this severe service, if the picks are used in the roller for a considerable length of time.

Cost of Resurfacing Old Limestone Macadam.—The data were taken from my time books and can be relied upon as being well within the probable cost of similar work done by contract under a good foreman. It will be noted that the cost of operating the roller is estimated at $10 per day. This includes interest and depreciation, as well as fuel and engineman's wages.

The road was worn unevenly, but as it still had sufficient metal left, very little new metal was added.

The roller used was a 12-ton Buffalo Pitts, provided with steel picks on the rear wheels. It required 80 hours of rolling with the picks in to break up the crust of a surface 19,400 sq. yds. in area, 2,400 sq. yds. being loosened per 10-hr. day. The crust was exceedingly hard and at times the picks rode upon the surface without sinking in, so that a lighter roller would probably have been far less efficient. In fact a 10-ton roller had been used a few years previous for the same purpose at more than double the expense per sq. yd., I am told. The picks simply open up cracks in the crust to a depth of about 4 ins. and it is necessary to follow the roller with a gang of laborers using hand picks to complete the loosening process. The labor of loosening and spreading anew the metal was 1,880 man-hours, or a trifle more than 10 sq. yds. per man-hour. About 60% of this time was spent in picking and 40% in respreading with shovels and potato hooks.

After the material had been respread, a short section was drenched with a sprinkling cart, water being put on in such abundance that when the roller came upon the metal, the screenings which had settled to the bottom in the spreading process were floated up into the interstices. The roller and sprinkling cart were engaged only 63 hours in this process, 3,000 sq. yds. being rolled per 10-hr. day; an exceptionally fast rate. The rapidity of rolling was

due to four factors: 1. The great abundance of water used, the water haul being very short. 2. The unyielding foundation (Telford) beneath. 3. The abundance of screenings and fine dust, the road not having been swept for some time. 4. The great weight of the roller, which was run at a high rate of speed. I am not prepared to say that longer rolling would not have secured a harder surface, but I doubt very much whether it would. The metal, I should add, was hard limestone. Summing up we find the cost of resurfacing this road per sq. yd. to have been as follows:

	Cts., per sq. yd.
Picking with roller, at $1 per hour	0.40
Picking by hand labor at 20 cts. per hour	1.20
Respreading by hand labor, at 20 cts. per hour	0.80
Rolling with roller, at $1 per hour	0.33
Sprinkling with cart, at 40 cts. per hour	0.13
Foreman, 143 hours, at 30 cts., for 19,400 sq. yds.	0.44
Total	3.30 ¢

At this rate a macadam road 16 ft. wide can be resurfaced for little more than $300 a mile. The frequency with which such resurfacing is necessary will, of course, depend upon several factors, chief of which are the amount of traffic and the quality of road metal. I should say that five years would not be far from the average for a country road built of hard limestone. Unless the road has had an excess of metal used in its construction, new metal should be added at the time of resurfacing to replace that worn out.

I am unable to see how any system of continuous repair, with its puttering work here and there, can be as economical as work done in the manner above described. I would not be understood, however, as favoring an entire neglect of the road between repair periods. At times of heavy rains and snows, ditches and culverts need attention and there should be someone whose duty it is to look after such matters. What I do question is the economy of having a man continuously at work putting in patches upon the road.

Low as the above costs are, much lower costs are attainable, using a scarifier, as previously described, or using a harrow, as described in the next paragraph.

Cost of Repairing Sandstone Macadam, Albion, N. Y.—Using the method that I am about to describe, Mr. P. J. Stock succeeded in picking, resurfacing and rolling a stretch of sandstone macadam 18 ft. wide by 1,000 ft. long in two 10-hr. days; one day in spiking up the old surface with the picks in the steam roller and one day in rerolling. As the surface was loosened to a depth of about 4 ins., it will be seen that over 200 cu. yds., or 1,800 sq. yds., of macadam were compacted by the 15-ton roller in 10 hrs. The point to which I wish to call attention is not so much the extraordinary rapidity of the rolling as the very ingenious method devised by Mr. Stock for completing the loosening of the macadam after cracking it up with the roller spikes. For this purpose Mr. Stock built a heavy harrow,

similar to those used on farms, Fig. 4, showing its detail design. By turning the harrow upside down it rides on the runners shown in the figure, and is thus transported when not in use. A heavy team of horses is used to drag the sharp-pointed harrow over the macadam after it has been loosened as much as possible with the spikes of the steam roller. The spikes in the harrow not only com-

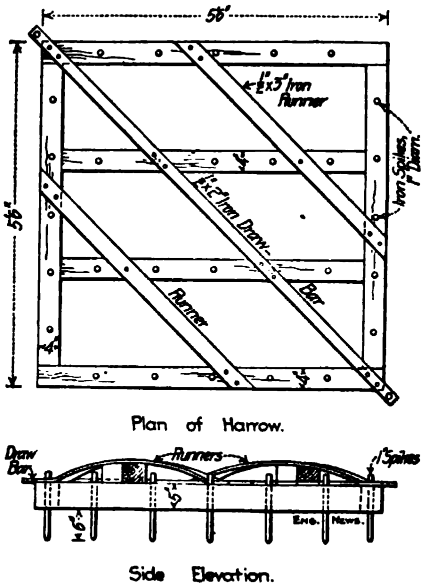


Fig. 4. Harrow for Scarifying.

plete the breaking-up of the crust as well as could be done by men using picks, but in addition the spikes spread the loosened stone, filling up all low places.

The total cost of resurfacing was:

	Cts., per sq. yd.
Roller and engineer at $1 per hour picking........	0.5
Roller and engineer at $1 per hour re-rolling......	0.5
Sprinkling, with cart, 40 cts. an hour (1 day)....	0.2
Harrowing, team and driver 30 cts. an hr. (2 days)	0.3
Total	1.5

At this rate a macadam road 16 ft. wide and a mile long can be resurfaced for less than $140. The cost of resurfacing has, there-

fore, been only $30 per mile per annum, since resurfacing has been necessary only once every 5 yrs.

It will be noted that the cost of picking (with roller) and harrowing was 0.8 ct. per sq. yd.

In addition to the labor item there were some 75 cu. yds. of stone furnished, which it was estimated would bring the road up to its original crown. The stone cost about $60, delivered, and was spread by two men in two days at a cost of $6. By using a "leveler" the item of spreading could have been reduced to $1.50.

For new materials we have, therefore, a trifle over $60 per mile per annum, making a total of about $90 per mile per annum for labor and material for resurfacing a Medina sandstone road. Of course, the loss of material by wear was not accurately measured, but it was less rather than more than the amount put on for repairs. At this rate, the annual vertical wear was about 0.2-in. over the whole surface.

This was a main traveled street, where farmers' teams enter the village.

Cost of Resurfacing Macadam and Data on Compression of Broken Stone.—Mr. F. G. Cudworth gives the following data. An old macadam road was resurfaced with trap rock to the depth of 3 ins. after rolling with a 10-ton steam roller. It required 3.9 ins. of loose trap and 2.1 ins. of screenings to make the 3 ins. of compacted macadam, according to Mr. Cudworth, but there must have been an error in his estimate of the final thickness of the resurfacing (and it is a very easy matter to err in measuring rolled macadam). Possibly he did not measure the thickness of loose screenings left on the macadam, for 2.1 ins. of screenings is more than sufficient to fill the voids in 3 ins. of compacted stone. The steam roller averaged 472 sq. yds. or 40 cu. yds. of macadam per 10 hrs., at a cost of 2¾ cts. per sq. yd. for rolling and sprinkling. The cost of rolling and sprinkling was distributed as follows, and it should be noted that it does not include any allowance for rent of roller. On the other hand it is rare that a fireman is employed in addition to the engineman, and it is not always that the full wages of a night watchman are charged to the roller:

Engineman	$ 3.00
Fireman	1.50
Coal and oil	4.00
Sprinkler	3.00
Watchman	1.50
Total per day	$13.00

The total cost of resurfacing was as follows, not including cost of stone:

	Cts. per sq. yd.
Scraping and sweeping	2.00
Picking up old surface	1.50
Spreading stone	2.00
Rolling and sprinkling	2.77
Total per sq. yd.	8.27

As will be seen by comparison with data previously given, this

cost of 8.27 cts. per sq. yd. is inordinately high, and shows both lack of good management and of knowledge of how to do such work economically.

Mr. W. C. Foster gives the following data: It was found that 7.38 ins. of loose trap rock on an old macadam pavement were rolled down to a thickness of 6 ins. under a 12-ton roller, a ratio of 1¼ cu. yds. of loose stone to 1 cu. yd. rolled. It was found in another case that 5.67 ins. of loose trap were rolled down to 4 ins., a ratio 1.42 to 1. The stone in both cases was trap, 1⅛ to 2¼-in. size. It was found that 1 cu. yd. of blue limestone screenings, sufficient to cover the rolled trap to a depth of 1.7 ins. over 21 sq. yds., was sufficient to bind 21 sq. yds. of 4-in. or 6-in. macadam. The loose stone and the screenings were measured in cars. I do not think that 5.67 ins. of loose trap can possibly be rolled down to 4 ins., furthermore I am sure that it takes more screenings to bind a 6-in. macadam than a 4-in. macadam. Mr. Foster says that in this work a 12-ton roller averaged 314 sq. yds., or 52 cu. yds., of 6-in. macadam per 10-hr. day.

Cost of Repairing Macadam in Ireland. —In *Engineering-Contracting*, Sept. 2, 1908, there is an excellent article on the methods of scarifying and rolling macadam roads in Ireland, also some costs, by Mr. E. A. Hackett. A brief abstract of the costs is as follows:

Common laborers, per day	$0.52
Foremen, per week	6.00
One horse cart and driver, per day	1.25
Engineman on roller, per day	1.25
Flagman and timekeeper, per day	0.87

Coal costs $5.50 per long ton at the railway station, and a 15-ton roller consumes one-third ton per day.

Mr. Hackett states that in Tipperary county there are 1,500 miles of macadam roads, of which 300 miles are main roads. The population is 90,000, and the area of the county is 1,000 sq. miles. The traffic is not severe, practically all in one horse carts carrying loads of 1 to 1½ tons on a pair of wheels.

From his data it can be deduced that the cost of repairing a macadam road 16 ft. wide is about $260 per mile per annum, there being 0.12 cu. yd. of broken stone used per sq. yd. of road for each resurfacing every five years, which is equivalent to 1,120 cu. yds. of stone per mile every five years, or 224 cu. yds. per mile per annum. Since the steam roller averaged about 50 cu. yds. of loose stone compacted per day, it is a simple matter to estimate the cost of such repairs under American conditions as to wages.

All the stone was quarried and broken by hand, and the following was the cost per cu. yd. loose measure, wages being as above given:

	Per cu. yd.
Surface damage to quarries	$0.04
Quarrying and breaking	0.46
Hauling	0.15
Spreading, watering and sweeping	0.12
Recarting stones, removing scarified materials	0.10
Rolling	0.17
Contingencies and profit	0.10
Total	$1.14

It is noteworthy that, in spite of the fact that wages were about one-third what they are in America, the unit cost of this work is almost as great as it is in America.

Mr. Hackett is strongly in favor of this intermittent system of repairs, instead of the old continuous or "patching system." He is also in favor of a 15-ton roller, and states that it will do 50% more work than a 10-ton roller, due to its wider tires.

Cost of Maintaining Macadam Roads, Massachusetts.—The annual reports of the Massachusetts Highway Commission show that the cost of "ordinary repairs" of macadam roads, whose age ranges from 1 to 15 years, averages about $100 per mile per year, excluding the cost of resurfacing. A small per cent of the macadam roads are now being resurfaced annually, this work being classed as extraordinary repairs. From data thus far obtained it is estimated that the maximum cost of all repairs—ordinary and extraordinary—will not exceed $200 per mile, unless the destruction occasioned by automobiles shall materially increase the cost of maintenance. The standard Massachusetts road is macadamized 15 ft. wide.

Cost of Repairing Macadam in Massachusetts.—The repairing on 550 miles of macadam roads averaged less than $100 per mile for the year 1904, although the first of these roads was 10 years old. But this does not include any general resurfacing.

In the report for 1902 data on the cost of repairing three heavily traveled roads leading into cities are given.

Road.	Age, yrs.	Length.	Width.	Per sq. yd. per year, cts.	Tons stone per sq. yd. per yr.	Cost per ton in place.
Leicester	6	3,150	24	5.17	.03	$1.70
West Fitchburg..	7	2,200	15	5.15	.023	2.23
Beverly	6	2,150	18	5.20	.03	1.80

None of these roads had been repaired since the day it was built. The Leicester road leads into Worcester, and is much more heavily traveled than ordinary country roads.

During 1905 the commission caused to be repaired 580.7 miles of roads, the average cost being $96.07 per mile.

A total of 13½ miles of road was resurfaced with broken stone; the cost of doing this is shown in the table below.

In Table III it is assumed that a cubic yard of stone weighs 1¼ tons, and that the loose broken stone shrinks 33 per cent under the compacting force of the roller.

The high rate of wear shown in Auburn and Hadley is due to strengthening the road, when resurfacing, by an increased depth of broken stone; the high rate of wear in Quincy and Chelsea is due to heavy traffic; in Sturbridge, to a poor grade of stone used in the original construction. In the case of Marion and Rochester, the original road was macadamized by those towns in 1896. In Hadley, $932 was used for side drains and in strengthening the road.

TABLE III.—COSTS OF RESURFACING 14 MACADAM ROADS DURING 1905.

Town or City.	Year of Lay-out.	Length (Feet)	Width (Feet)	Broken stone per Square Yard per Year (Tons)	Per Square Yard per Year (Cts.).	Broken Stone in Place, per Ton.
Auburn*	'95-6-7	10,168	15	.03	5.62	$1.49
Chicopee†	'97-8-9	3,550	15	.02	4.40	2.04
Chelsea†	'01	3,053	24	.11	18.32	1.60
Beverly†	'95	3,025	18	.01	3.22	2.09
Great Barrington†	'94-6	9,368	15	.01	2.47	2.24
Hadley†	'94	2,788	15	.04	9.29	1.78
Marion*	'93	782	15	.01	2.98	1.75
North Adams†	'94-6	9,000	15	.01	2.90	2.09
Pittsfield†	'94-8	6,842	15	.01	2.31	2.14
Sturbridge*	'97	3,094	15	.03	4.85	1.50
Quincy†	'99	2,606	30	.03	7.09	2.20
Rochester*	'03	3,345	15	.02	4.17	1.75
Townsend†	'96-7-8	3,700	15	.01	3.31	1.91
Westport†	'94	3,015	18	.02	5.19	2.35

*Local stone used.
†Trap rock used.

Cost of Calcium Chloride as a Dust Preventative.*—During the summer of 1907, the U. S. Office of Public Roads undertook a series of tests to determine the value of calcium chloride as a dust preventative. These tests were made on the portion of the macadam driveway in the Agricultural Department Grounds, in Washington, D. C.

The roadway on which the test was made is built of trap rock, held in position by a soft limestone binder. The screenings of this binder pulverized rapidly under traffic, forming a light dust which passing vehicles continually raised into the air. It was then carried away by the wind. In this way the road was becoming stripped of its binding material.

In preparation for the treatment all dust, and dirt were scraped from the surface of the roadway. A solution was prepared by mixing 300 lbs. of commercial calcium chloride (granular, containing 75 per cent calcium chloride and 25 per cent moisture) with 300 gals. of water in an ordinary street sprinkler, care being taken to agitate the liquid thoroughly before applying it to insure a uniform solution. It was then applied from one sprinkling head, and the sprinkler passed slowly back and forth over the road to facilitate the complete absorption of the solution. Each application consisted of 600 gals. over an area of 1,582 sq. yds., or 0.38 per sq. yd.

The first application was made July 13, 1907, followed by a similar one July 15, to increase the efficacy of the treatment. The effect of the first two treatments was marked. No auxiliary sprinkling was necessary for some time, the light rains falling at intervals

*Engineering-Contracting, July 1, 1908.

supplying all the moisture required. The untreated portions of the driveway lying parallel to 12th and 14th streets, were sprinkled daily and vehicles raised a perceptible dust, although the traffic over these wings was much less heavy than that on the treated portions.

During this time the appearance of the roadway varied perceptibly in color according to the moisture in the road surface, ranging from a light gray when dry to a peculiar grayish brown when moist. The brown shades were deepest over the portions traversed by the wheels of vehicles. The texture of the road surface was completely changed after the application of the calcium chloride. Before treatment, raveling was excessive in spots and the whole surface seemed loosely knit together. After the application on July 15 this condition changed and the road surface became smooth, compact and resilient.

The third treatment was given Aug. 3, as certain points exposed to the most severe wear were showing signs of raveling. The phenomena following this treatment were not unlike those attending the first set of applications and repeated themselves as later applications were made, though no further treatments were given until the condition of the roadway seemed to demand it. Such auxiliary sprinkling as was necessary consisted in the application of about 0.2 gal. of water per square yard at a time.

The accompanying table shows the cost of applications. The calcium was donated by a manufacturing chemical company of Baltimore, Md., and is charged at the rate of $16 per ton, f. o. b. cars at Baltimore. A freight charge of 13 cts. per hundredweight is added to place the material on the ground. This makes the total cost of the calcium chloride $18.60 per ton.

	Total.	Per sq. yd.
600 lbs. calcium chloride	$5.586	$0.00352
3 men, 1½ hours	0.675	.00042
1 horse sprinkling wagon, 1½ hours	0.525	.00033
Total (1,582 sq. yds.)	$6.786	$0.00427

Total cost of five applications was $33.90, or $0.0235 per square yard. Labor was paid 15 cts. per hour and 35 cts. per hour was paid for the sprinkling wagon.

The specific gravity of these solutions ranged from 1.053 to 1.060. Some variation was unavoidable, as the calcium chloride in some of the barrels had absorbed a large amount of moisture from the atmosphere. In such cases the actual percentage of the chemical to 300 lbs. was less than where little or no moisture had been absorbed.

At the time of the last application several hundred pounds of the salt remained unused. This was divided as nearly as possible into two parts, to be applied to the two wings of the driveway lying parallel to 12th and 14th streets. The east wing received a treatment of 0.28 gal. per sq. yd. of a solution the specific gravity of which was 1.145 and the west wing a similar application of a solution having a specific gravity of 1.121. No further sprinkling was

found necessary for the remainder of the season upon these branches of the main driveway.

Cost of Tarring Macadam, Michigan.*—Mr. Charles R. Wrightman gives the following relative to 16,620 sq. yds. of work done in South Haven, Mich.

The local gas company furnished the tar. The plant consisted of a roofer's tar kettle which held about 150 gals. of tar; six galvanized sprinkling cans, each of which held 14 quarts; the sprinklers were removed and a flat spout with ⅛-in. opening 6 ins. long, put in place of the sprinklers; one dozen fiber stable brooms.

The kettle was set up about midway in the first block of Center street, which was a new macadam street, 50 ft. wide, from which travel had been excluded, and which had been allowed ten days to dry.

Two barrels of tar were placed in the kettle and brought to the boiling point, then it was drawn into the sprinklers, Fig. 5, two of which were carried by each of three men and poured with a

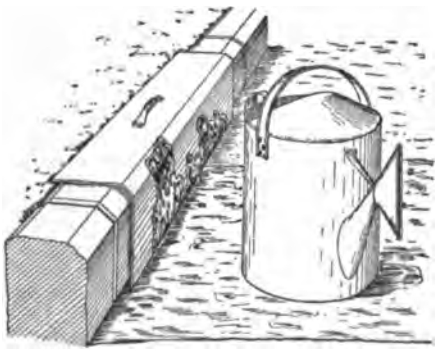


Fig. 5. Tar Spreader and Curb Protector.

sweeping motion from side to side, each man covering about one-third of the width of the street, thus carrying a straight face of tar up the street. Working on the tarred surface and closely following the sprinklers, was a man with a fiber broom who smoothed out the thick spots and rubbed the tar in wherever dust or depression prevented a good contact. Immediately following, came two men, who with scoops, uniformly covered the tar with limestone screenings or "crushed stone sand" to the depth of from ½ in. to ¾ in., which was then immediately rolled with a 10-ton steam roller (weight not essential), and the street then thrown open to traffic.

The results of this work are that the street is free from stone dust and is dry in an incredibly short time after rains, and I have

Engineering-Contracting, May 8, 1907.

noticed that snow melts and runs off much faster than it does on brick streets and that a few hours of thaw clears the street so there is nothing to freeze when night and a lower temperature comes on. We now treat the macadam before throwing it open to traffic, as we found on Dyckman avenue, which had been in use about three months, that the mud and dirt interfered seriously and we did not get as good adhesions on this street. In this case the surface was first swept clean with steel brooms and all spots of scale or droppings, scraped off with a scraper made by straightening the shank of a garden hoe until the blade was in line with the handle. While it was a decided improvement to this street, the results were not as satisfactory as on the new surfaces, and, if possible, I would break up and remetal a street before applying tar.

In heating, we found it best to put tar into the kettle with buckets about as fast as it was drawn off into the spreading cans, thus doing away with the necessity of spreaders waiting for "hot stuff." The kettle should be on wheels so that it could be moved without drawing off the tar and extinguishing the fires, as was necessary with the kettle which we used.

On about 1,000 sq. yds. of the work, torpedo sand was used for surfacing in place of limestone screenings. The results were favorable but not as satisfactory as when screenings were used, it being found that it was very hard to get the sand dry enough properly to take up the free tar; but I believe if good, sharp torpedo sand, free from moisture, could be obtained, the results would be satisfactory.

The unrefined tar which was used on this work is a very active irritant and will draw a blister in short order. In order to obviate this, men handling tar should keep their hands and faces well smeared with fresh lard. On the above work, we used about 15 lbs.

In order to keep from smearing the curb stone with tar, I had made two sheet iron guards, Fig. 5, taking a piece of heavy galvanized iron, 16 ins. wide and 8 ft. long, bent in the middle to a right angle and provided with a strap handle on top. This was laid on the curb with one leg of the angle perpendicular and against the face of the curb, the other lying on and projecting over the top. The spreaders moved it along each time a can full of tar was spread. This eliminated the unsightly splotches.

Some judgment has to be exercised on the work of spreading tar. Apply more where the surface is open or not "puttied," and less where surface is hard and close. Good intelligent men should be employed as spreaders as much of the economy in tar is dependent on them. Too much screenings is preferable to too little, and, after rolling, the surplus may be swept up and used again.

A close watch must be kept on the kettle as unrefined tar is highly inflammable, and, after it starts to boil, will climb over the top of the kettle very quickly. In case of fire, sand should be thrown into the kettle until the fire is smothered.

The gang was as follows per day of 10 hrs.:

	Per day.
1 kettleman (acts as foreman)	$ 2.25
2 barrel men, at $2.25	4.50
3 men sprinkling tar, at $2.25	6.75
1 man brooming tar, at $1.75	1.75
2 men spreading screenings, at $1.75	3.50
1 team hauling tar and screenings	3.50
Total	$22.25

The team hauled tar, wood and screenings and moved kettle from place to place. At times it became necessary to put on an extra team to keep the work supplied with screenings, but ordinarily one team took care of the whole work.

This gang averaged about 1,500 sq. yds. (700 gals. tar) per day, and the cost was as follows:

	Per sq. yd.
Labor:	
Kettleman	$0.0015
Barrelmen	0.0030
Men sprinkling tar	0.0045
Man brooming tar	0.0012
Men spreading screenings	0.0023
Team	0.0023
Total labor	$0.0148
Materials:	
0.466 gals. tar, at 3 cts.	$0.0140
0.0175 cu. yd. screenings, at 90 cts.	0.0158
Total materials	$0.0298
Grand total	$0.0446

In addition to the above, the city roller was used a total of 15 hrs., and, if we assume $1 per hr. for the roller, the cost of rolling was less than 0.1 ct. per sq. yd., which, added to the above 4.5 cts., gives a total of 4.6 cts.

With a portable kettle, a saving of 20 per cent on labor would have been effected, by doing away with the time lost by all hands in moving the kettle.

Being so well pleased with tar on macadam, Mayor C. E. Abell authorized an experiment on clay. Accordingly, Chambers street, which is a porous yellow clay street, having a width of 40 ft. between wood curbs, was shaped up with a road grader, making a crown of about 20 ins. and rolled with the 10-ton steam roller. Tar and screenings were applied in the same manner as on the macadam streets, and the results have been surprising. This street, which has been practically impassable every spring and fall, is now perfectly dry and smooth, and a passerby would suppose it was macadamized. In two or three places where light, uncompacted dust was on the surface, the tar and stone covering has been broken, but otherwise it is in perfect condition, shedding the water nicely, and bids fair to be a good hard road for some time. The cost of the tar and stone was practically the same as on macadam, but in doing this work, we have learned that the preparation is the essential point. The road should be shaped and carefully smoothed by rolling and wetting until no loose or dry powdered clay remains; and, just the reverse

from macadam which must be perfectly dry, the clay should be slightly moist, as the hot tar on dry, powdered clay rolls up into minute balls and does not spread out as it should in a film or sheet. In every instance, the tar should be as near the boiling point as possible, when applied to the street.

Cost of Tarring Macadam, Massachusetts.*—The following data relate to some experimental road treatments made last year by the Metropolitan Park Commission on roadways at Revere Beach Parkway, Massachusetts. The experiments were made with a specially prepared coal tar known as Tarvia, and a total length of 3½ miles of roadway was treated with this material, the work being done by day labor under the supervision of the Engineering Department of the commission. The work was begun Aug. 25, 1906, and was completed Sept. 29, a total of 67,434 sq. yds. of roadway having been treated at a cost of $4,494.

The force employed consisted of one foreman and seven laborers. A street sweeper, a sand sprinkler, a double team and one steam roller were used in the work.

The Tarvia was delivered in tank wagons, and the cost of hauling same was paid by the commission. The same men were used for the various operations of cleaning the road, spreading the Tarvia and covering with screenings. The detailed costs of the work are given by Mr. John R. Rablin as follows:

	Per sq. yd.
Materials:	
Tarvia, 0.4 gals.	$0.0262
Stone screenings, 0.015 tons	0.0184
Total materials	$0.0446
Labor:	
Preparing roadway	$0.0086
Applying Tarvia	0.0057
Applying screenings	0.0062
Rolling	0.0047
Total	$0.0252
Grand total	$0.0698

Thus a new smooth surface was formed over the bare stone, which seems to be holding well; the dust nuisance was abated, and in time of wet weather the roadways were entirely free from mud. Regarding the permanency of the results obtained Mr. Rablin writes us that the work which was done last fall has proved very satisfactory, and the commission is now treating other roads. In a subsequent issue if *Engineering-Contracting* (Dec. 18, 1907), Mr. Rablin states that about half of the above yardage was treated again with Tarvia, due to the fact that it had begun to show signs of wear.

In 1907, about 90,000 additional sq. yds. of roadway were treated with Tarvia, the average cost being as follows:

	Per sq. yd.
Tarvia, 0.45 gal.	$0.0316
Stone screenings, 0.016 tons	0.0219
Labor	0.0196
Total	$0.0731

**Engineering-Contracting*, June 12, 1907.

The organization and wages were as follows:

	Per day.
1 foreman	$ 2.75
1 double team (2 horses and driver)	5.00
1 single team (1 horse and driver)	3.50
7 laborers cleaning road, at $2	14.00
5 laborers spreading tar, at $2	10.00
3 laborers spreading screenings, at $2	6.00
Total	$41.25
1 steam roller, assumed at	10.00
Total	$51.25

I have assumed the $10 daily rate for the steam roller (including coal, engineman, etc.), for Mr. Rablin does not state its rate.

Since the average cost of labor was 1.96 cts. per sq. yd., we infer that about 2,600 sq. yds. were treated per day, for $51.25 ÷ $0.0196 = 2610. If this inference is correct, we have the following itemized cost of the labor:

	Per sq. yd.
Foreman	$0.0011
Teams, sweeping, sprinkling sand, etc	0.0033
Laborers cleaning road	0.0053
Laborers spreading tar	0.0038
Laborers spreading screenings	0.0023
Rolling	0.0038
Total	$0.0196

It will be noted that the above contains no item for cost of heating the tar nor for hauling it.

Cost of Tarring Macadam, Jackson, Tenn.*—Mr. Logan Waller Page, Director, Office of Public Roads, gives the following data of work done under Mr. Samuel Lancaster's direction.

The macadam streets in the business center of Jackson were built originally of the hard silicious rock known as novaculite. About May, 1905, after fifteen years of wear repair of these streets became necessary.

The old surface was first swept clean with a horse sweeper. This was done because tar will not penetrate a road surface which is covered with dust and loose materials.

Next, the surface was loosened by means of spikes placed in the wheels of a 10-ton steam roller, the street reshaped, and new material added where needed.

The road was then sprinkled, rolled, bonded and finished to form a hard, compact, even surface, and allowed to dry thoroughly before either tar or oil was applied, for these substances cannot penetrate a moist road surface. The best results are obtained when the work is done in hot, dry weather, and accordingly the tar was first applied in August.

Other sections of streets and roads were built of new material entirely and according to well-known principles of macadam construction, but no tar or oil was put on them until after they had

**Engineering-Contracting,* July 4, 1906.

been subjected to traffic. Sections of country roads which had been built for periods of from one to two years were also treated with tar and oil.

The tar used was a by-product from the manufacture of coke and was practically free from moisture. It was received at the railway station in standard steel tanks of about 8,000 gals. capacity. A portable boiler was connected with the steam coils of these tank cars to heat the tar and keep it hot, thus saving time in bringing it to the temperature desired for spreading on the road. It was then taken from the tank cars and poured into a cylindrical tank wagon of 500 gals. capacity by means of a hand-lever pump. This portable tank had a small fire box under one end with a flue running directly beneath the tank to a smokestack at the other end. A fire was kept in the fire-box and the tar brought to a temperature which generally reached 210° F., but when placed on the road it was reduced to a temperature of from 160° to 190° F. The hottest tar produced the best results.

A horizontal pipe with an adjustable, longitudinal slot, attached to the rear of the wagon and extending down close to the surface of the road, was first used to spread the tar, but this became clogged and did not give an even flow. It was therefore abandoned, and in place of it a piece of four-ply 1¼-in. rubber hose was attached to the wagon. This hose had a nozzle of 1-in. pipe, slightly flattened at the end to produce a broad stream, and was provided with a valve for controlling the flow. The tar was spread with this hose over a radius of about 15 ft. of road surface.

Laborers, with street cleaners' brooms of bamboo fiber, followed the tank and swept the surplus tar ahead. They spread it as evenly and quickly as possible, and in a layer only thick enough to cover the surface. One side of the street was finished at a time, and barricades placed to keep off the traffic until the tar had had time to soak into the surface. The time allowed for this process was varied from a few hours to several days. From the results obtained it can be stated that, under a hot sun, with the road surface thoroughly compact, clean, and dry, and with the tar heated almost to the boiling point and applied as described above, the road will absorb practically all of it in eight or ten hours.

A light coat of clean sand, screenings, or the clean particles swept from the surface of the road, may then be spread as evenly as possible and rolled in with a steam roller. These different top layers were applied to various sections, and in one case the road was left to dry without spreading anything except the hot tar. In another instance sand was applied to the tar within two hours, which resulted in the absorption of the tar by the sand and lessened its penetration of the road surface. It was necessary to remove this sand-tar mixture, which peeled up under traffic. A sufficient amount of tar, however, had penetrated the surface of the road to make it waterproof, and after more than seven months of service this section of street is in good condition.

In spreading the coat of material for drying the surface of the

road and absorbing the surplus tar, only enough should be used to cover it lightly, as, after rolling, this surplus material will be washed or blown away, or it may be removed with street sweepers and the surface left smooth and clean.

After more than seven months, including the winter season of 1905-6, the tarred streets and roads are still in excellent condition. They are hard, smooth and resemble asphalt, except that they show a more gritty surface. The tar forms a part of the surface proper and is in perfect bond with the macadam. Sections cut from the streets show that the tar has penetrated from 1 to 2 inches, and the fine black lines seen in the interstices between the individual stones show that the mechanical bond has been reinforced by the penetration of the tar. The tar is a matrix into which the stones of the surface are set, forming a conglomerate or concrete. A second coating applied a year after the first would require much less tar than the first, as the interstices of the rock would then be filled with tar.

On five different sections, having a total of 13,235 sq. yds., the average cost of the labor was about as follows:

	Per sq. yd.
Labor, sweeping, at $1.25 per 10-hr. day	$0.0014
Filling tank, heating tar, and hauling to the road	0.0012
Labor, applying tar	0.0030
Labor, applying sand or screenings	0.0030
Total labor	$0.0086

The total labor was, therefore, less than 1 ct. per sq. yd. Negro labor was used, at $1.25 for 10 hrs., and teams were paid $3 per day. The average quantity of tar was 0.45 gal. per sq. yd. The labor cost of heating, hauling and applying the tar was 0.42 ct. per sq. yd., as above given, or practically 1 ct. per gal. of tar, exclusive of the labor of sweeping and of applying sand; but, including those two items of labor, the labor cost was practically 2 cts. per gal. of tar.

Cost of Oiling Macadam, Jackson, Tenn.*—Mr. Logan Waller Page gives the following. (For comparative data on tarring macadam at the same place and time, see page 300.)

Seven tank cars of oil, given by some Texas and Louisiana companies, were used at Jackson. It varied in quality from a light, crude oil to a heavy, viscous residue from the refineries. Over 7 miles of country road and several city streets were treated.

At first, some of the lighter crude oils were applied with the same tank wagon that was used for the tar. Hose and brooms were used to spread the oil, and practically the same process was followed as with the tar. The oil soaked into the macadam very quickly and left no coating on top. It caused the light covering of sand which was applied to pack down and gave the road a dark color.

**Engineering-Contracting*, July 4, 1906.

It was soon noticed that the preliminary sweeping was unnecessary, as the roads were practically free from dust, and oil and would penetrate the surface. The removal of detritus was a loss to the road, which had to be replaced by sand to prevent excessive wear on the stone. It was later found that it was much cheaper to use an ordinary street sprinkler than the tank wagon, and in this case spreading the oil with brooms was unnecessary.

The crude oil was used cold, and the cost of applying it with the different methods used is given below.

On a city street 8,266 sq. yds. were treated at the rate of 0.48 of a gal. of oil per sq. yd. with the use of the tank wagon and hose. The cost of labor per square yard was as follows:

	Per sq. yd.
Sweeping street	$0.0011
Filling tank and hauling	0.0008
Oiling street	0.0024
Spreading sand	0.0014
Total	$0.0057

On a country road 2,000 gals. were spread, covering 5,206 sq. yds., at a rate of 0.38 of a gal. per sq. yd. The average haul was 1 mile. Only the manure was removed before oiling. The cost of labor averaged $0.0033 per sq. yd.

It took 9 men 30 mins. to spread 500 gals., or one tank load, and the 18-ft. road was covered at the rate of 1,860 ft. per hour. It took 28 mins. to fill the tank with oil.

With an ordinary street sprinkler, one man and team spread one load of 600 gals. of oil in 15 mins. The sprinkler thus spread 600 gals. in one-half the time that it took 9 men, with the tank wagon, to spread 500 gals.

The heavy residual oils were so thick when cold that they would not run through a 2-in. fire hose attached to the rear of the tank wagon, and it was necessary to pump the oil upon the road. The pump with which the tank was charged was used for this operation. Only one tank wagon (500 gals.) of the heavy oil was applied cold. It formed a thick, sticky mass on the top of the road that rolled about under pressure and seemed to have an unlimited capacity for absorbing the sand which was spread upon it. The street had to be cleared of the greater part of this mass of oil and sand within a short time.

After this experience the oil was heated in the tank car by steam, and better results followed. It still ran slowly through the hose and nozzle, and it was found cheaper to take off the hose and allow the oil to flow from the outlet of the tank wagon directly upon the road, where the men swept it over the surface with brooms. An air pump was tried, to increase the flow of the tank wagon by pressure, but the tank was not tight enough to prevent the escape of air, and this experiment was unsuccessful.

Twenty-four hours after the application of the residual oil it was covered with sand or limestone screenings, and in four days it was

firm enough to bear traffic without showing any wheel tracks. It shed the water well in a violent rain storm.

The following was the labor cost per square yard of putting residual oil on city streets with the use of the tank wagon. Approximately 0.71 gal. of oil was used per square yard:

	Per sq. yd.
Sweeping street	$0.0010
Heating, loading and hauling	0.0017
Oiling street	0.0029
Spreading sand	0.0022
Total	$0.0078

Excellent results can be secured by the use of this heavy residual oil if it can be applied to the surface of the road at a temperature approaching the boiling point.

The medium grade of oil, which was tried next, is classed by the refiners as "steamer oil." It was heavy enough to leave a slight coating on the surface, which made a very compact covering with the dust of the road. Only the heavy matter was removed from the surface of the road before applying the oil. It was heated by steam in the car, but was not hot when it reached the road. It was not safe to build a fire in the tank wagon, and the best road surface was obtained where the oil was at the highest temperature. Some method of heating the oil safely on the road would greatly improve the result. This could be accomplished with a steam traction engine having steam coils connected with the tank, the engine hauling and heating the tank while spreading the oil. Most of this oil was applied with the street sprinkler, and it sprayed readily when hot.

In applying the greater part of the oil on the country roads the following men and equipment were used:

	Per day.
1 foreman	$ 2.00
6 laborers, at $1.25	7.50
1 tank wagon	3.00
1 street sprinkler	3.00
2 firemen, at $1.50	3.00
1 ton coal	4.00
Total	$22.50

This force spread 3 tank wagons and 3 sprinkler tank loads, or 3,300 gals. per day, making the cost 0.7 ct. per gal. The 6 laborers (negroes) pumped the oil at the car and worked on the road. It will be noted that it required about 0.6 lb. coal to heat 1 gal. of oil.

No sweeping was done on the country roads except to remove manure and to spread the oil where it was inclined to puddle. No sand or other material was applied to the road after oiling.

More than seven months have now elapsed since the work was done. The light crude oil has produced little if any permanent results. The roads where it was applied are but slightly changed, and some dust arises on them from traffic. The only apparent result is a slightly darker color on the "shoulders" of the road, and

but little difference can be noticed between this and other sections of the road which were not treated. This oil was too volatile for the purpose, and where it has to be shipped for any distance does not justify the expense of using it.

The medium "steamer oil" from Texas has given good results. There is a thin surface coat of dust packed down that protects the stone from the grind and pounding of traffic. This effect is very noticeable in driving over it. The harsh grinding noise of the wheels, which is pronounced on the novaculite surface, disappears at once, and there is decided relief in driving upon it. It is practically noiseless. This coating is perhaps one-eighth of an inch thick, and is not a concrete, but compacted dust, which is made to cohere by the oil with which it is saturated. This road does not wash or "pick up," and the wear on the rock is much decreased.

Cost of Oiled Earth Street, Arkansas.*—Mr. Frank H. Wright gives the following:

The street in question (Helena, Ark.) was about 700 ft. long and was oiled for a width of 40 ft. The soil was a soluble yellow clay, and in heavy rainstorms there had always been much washing of the gutters and in the wagon tracks on the crown.

Preparatory to oiling, the street was thoroughly plowed twice for a width of 40 ft., the amount used for traffic, a small-pointed Avery plow with a steel beam being used. After plowing, a disc harrow was thoroughly applied, after which a toothed harrow was used until the street was like ashes. One team with a driver was used in this preliminary work, but a shaker was used with the plow. The plowing and harrowing consumed about two days.

The oil was brought to the street by a team carrying three 52-gal. barrels. To get the oil from the tank car a small lever pump was bolted to the floor timber of the car at the side of the tank, and a connection made to the inside of the tank by a siphon made of 2-in. wrought iron pipe and fittings. The driver with one man to pump was able to leave the street, go to the car and fill the three barrels and return exactly in 30 mins.

In applying the oil, a strip about 15 ft. wide was taken on each side of the street, the street not being closed to traffic, and three men, each equipped with a 2-gal. sprinkling can, with the spray removed, poured the oil on the pulverized surface. Each man worked in his own section, about 20 ft. long, the driver filling the sprinklers by pumping from the barrels with a tin oil pump.

A load of coarse sand was dropped about every 50 ft. on the oiled strip, and, during the absence of the wagon in refilling the barrels, this sand was spread by the men in the same manner that sand is applied over a newly grouted brick pavement.

After one side had been oiled and sanded, a strip on the other side was treated in a like manner, and the center strip was again plowed and harrowed, having become compacted by traffic. After the center strip had been treated the whole strip was gone over

---

**Engineering-Contracting*, Nov. 21, 1906.

with a toothed harrow, and was then oiled and sanded a second time, but was not harrowed again.

The work was done in the first week of July and until recently there had been comparatively little dust and no mud, nor had there been any more washing where formerly it was excessive after a hard rain. There have been several hard rains this summer, one coming soon after the street was treated.

In applying the oil it took the three men exactly one hour to dispose of the three 52-gal. barrels of oil over a surface of 15 ft. x 100 ft., or 1,500 sq. ft. One man scattered with a shovel one wagon-load of sand (about 24 cu. ft.) over an area of 50 ft. x 60 ft., or 3,000 sq. ft., in 15 mins.

The gang was as follows:

	Per day.
1 foreman, at $1.50	$ 1.50
2 teams, at $3.00	6.00
3 laborers, at $1.25	3.75
Total	$11.25

It took this gang 3½ days to oil 3,110 sq. yds., the cost being as follows:

	Per sq. yd.
Laborers, at $1.25 per day	$0.0054
Teams, at $3.00 per day	0.0068
Foreman, at $1.50 per day	0.0017
Total labor	$0.0130
0.8 gals. oil, at 3 cts	0.0241
0.011 loads (24 cu. ft.) sand at 75 cts	0.0084
Grand total	$0.0463

Since a team and driver and one man to pump the oil could pump and deliver 6 bbls., or 312 gals. per hr., this item of cost was 0.14 ct. per gal. Since it took 3 men 2 hrs. to spread the 6 bbls., or 312 gals., the cost of spreading the oil was 0.24 ct. per gal., making a total of 0.38 ct. per gal., even with this crude way of spreading the oil with 2-gal. sprinkling cans.

Cost of Oiling Macadam, New York State.*—Mr. Arnold G. Chapman gives the following description of oiling certain New York state roads in 1906.

An ordinary 600-gal. steel tank on wheels was equipped with an "oil distributor" or sprinkler of the kind that has been developed in California for distributing heavy oils. The characteristic features of this type of sprinkler are that the oil is distributed directly downward upon the road surface and that the width of the application may be regulated from 18 ins. to 6 ft., as can also the amount of oil applied, by the manipulation of levers by the operator, who sits in the rear of the tank. From his position the operator can adapt the flow of oil both as to quantity and width, as the condition of the road may demand.

To unload the oil from the 6,000-gal. U. T. L. cars, in which it

*_Engineering-Contracting_, May 6, 1908.

was received, a diaphragm pump was used, fastened to the dome of the car. By means of an iron chute the oil was conveyed from the pump to the sprinkler tank. This method was rather cumbersome and unhandy and entailed the loss of too much time in setting up the pump and in unloading the oil, but it was the best and cheapest available at that time. However, it can be greatly improved upon when the oiling is undertaken on more than an experimental basis.

The oil used was that known as the Raglan oil, obtained through the Standard Oil Co., from their wells at Salt Lick, Ky., at a cost of 4.78 cts. per gal., f. o. b. at the various places where used. This is a crude oil, being black and heavy, due to the presence of asphalt, of which the producers claim a 30% to 35% base. When cold, the flow of oil is slow and sluggish, but when warm it flows with a reasonable degree of rapidity.

On the several sections of road treated the methods of application varied, some being sanded, others swept, and some treated, as left by the traffic. While the oil was being applied, traffic was not suspended, but the people chose the sides of the road not oiled, for a few days until the oil had been taken up by the surface and did not have a tendency to adhere to the vehicle tires and to be thrown upon the garments of the people riding or on vehicles. From observation during the experiments it was noted that the best results were obtained when the surface of the road was warm and dry and the day was also clear and warm.

About 18,700 gals. were applied to 8 different macadam and gravel roads, having an aggregate of 13½ miles, having an aggregate width of 10 ft., making an average of about 1,400 gals. per mile, or nearly 0.24 gals. per sq. yd. The average haul was 1½ miles.

Ordinarily the gang was one team (with driver) and one laborer to pump oil and to operate the levers of the oil distributor when sprinkling. The average labor cost per gallon was as follows, team receiving $4 per 8-hr. day, and laborer, $1.75:

	Per gal.
0.006 hr. team, at $0.50	$0.0030
0.007 hr. laborer, at $0.22	0.0015
Total	$0.0045

To this cost of approximately ½ ct. per gal. should be added the cost of supervision, and of plant charges.

The average cost per sq. yd. was as follows (excluding supervision):

	Per sq. yd.
0.24 gal. oil, at 4.78 cts.	$0.0115
Labor, 0.24 gals. spread, at 0.45 ct.	0.0011
Total	$0.0126

At 1¼ cts. per sq. yd., a mile of road 10 ft. wide was oiled for $75, not including supervision nor plant charges.

One stretch of gravel road 2.8 miles long and 8 ft. wide was oiled

with 3,400 gals. in 2 days at the following cost, although the oil was hauled an average of 2½ miles:

	Per gal.
0.0048 hrs. team, at $0.50	$0.0024
0.0048 hrs. pumpman, at $0.22	0.0010
Total	$0.0034

The cost per sq. yd. was:

	Per sq. yd.
0.26 gal. oil, at 4.78 cts.	$0.0124
Labor, 0.26 gal. spread, at 0.34 ct.	0.0009
Total	$0.0133

The item of supervision (including traveling expense) is given in none of the above summaries of cost, for it was exceedingly high (about 0.6 ct. per gal., or twice what the actual spreading cost), due to the fact that a state engineer accompanied the gang and traveled from road to road at an expense that would not ordinarily be called for except in cases of experimental work like this.

Cost of Oiling Macadam, Kansas City, Mo.*—Mr. W. H. Dunn gives the following relative to oiling 375,400 sq. yds. of park roads (macadam) in 1907. During the year most of the roads were given two treatments of residuum oil from the Kansas field. The price of the oil was 77 cts. per bbl. of 42 gals., or 1.84 cts. per gal.

The first treatment with oil, during May, June and July, cost as follows:

	Per sq. yd.
0.32 gal. oil, at 1.84 cts.	$0.0059
Labor and screenings	0.0089
Total	$0.0148

This is a trifle less than 1½ cts. per sq. yd.

The second oiling was done in August, September and November, covering 260,000 sq. yds. in addition to the 375,400 that had been oiled in the early summer, and the cost was as follows:

	Per sq. yd.
0.25 gal. oil, at 1.74 cts.	$0.0044
Supplies, repairs and screenings	0.0008
Labor	0.0030
Total	$0.0082

The limestone screenings formed a considerable part of the cost of the first oiling, but a very small part of the cost of the second oiling. It will be noted that the two oilings cost about 2¼ cts. per sq. yd. for keeping down the dust during the year. No sprinkling with water was necessary after a road had once been oiled. During the previous year, the cost of sprinkling 585,000 sq. yds. (including asphalt and creosoted blocks) with water had been 2.4 cts. per sq. yd.

The methods of unloading the oil, preparing roadway, spreading, were as follows:

Two steel receiving tanks, of 8,000 gals. capacity, were erected at

Engineering-Contracting, Jan. 22, 1908.

a total cost of $741.99, connected with a 4-in. pipe-line from receiving tank to the side track, permitting of unloading tank cars by gravity, the receiving tanks being also established at such an elevation as to permit loading the sprinkling carts by gravity from the receiving tanks. Two portable boilers were purchased at $67.50 each, for the purpose of heating the oil in tanks and in sprinkling carts. When the macadam was absolutely dry and hard, the entire surface of the roadway was swept clean of dirt and screenings. The sweepings were left along the edge of the gutter for protection to the cement work, then the oil was applied from the sprinkling-carts. To the regular sprinkling-carts was attached a tin trough, perforated with ¼-in. holes, to obtain an even distribution of the oil. The entire surface of the roadway was then flooded with oil and thoroughly broomed in, after which the sweepings from the gutter, with sufficient limestone screenings to form a slight dressing, were cast over the oil and thoroughly rolled with a steam roller.

The organization of the gang used in applying the oil was simply teams for ordinary city sprinkling wagons, usually from three to four teams, depending on the length of haul from the distributing plant, and from eight to ten ordinary laborers about equally divided between sweeping the screenings to the gutters ahead of the oiling and spreading the oil with brooms and casting the sweepings back over the oil after it was spread.

Cost of Tar Macadam, Massachusetts.*—Mr. Arthur H. Blanchard gives data upon which the following is based, relative to experimental work done by the Massachusetts Highway Commission in 1908.

Three methods of construction were used, which may be termed (1) the mixing method, (2) the grouting or penetration method, and (3) the Gladwell system.

By the Mixing Method.—With the exception of the addition of tar, the method of construction used was similar to that employed in the building of an ordinary macadam road.

After the subgrade had been thoroughly rolled, the No. 1 broken stone (varying in size from 1¼ to 2½ ins. in their longest dimensions) was spread to a depth of 6 ins. and rolled to 4 ins.

[Note.—While the statement is made that a 6-in. layer was rolled to 4 ins., no such compression as this is possible.]

Tar, which had been heated in an ordinary tar kettle to the boiling point, was then sprinkled on the rolled surface by means of dippers.

The No. 2 stone (varying in size from ½ to 1¼ ins. in their longest dimensions) was next deposited on dumping boards and thoroughly mixed with hot tar with the aid of rakes and shovels. This mixture was applied on the No. 1 course to a depth of 3 ins. and rolled to 2 ins.

A thin coat of dust, which would pass through ½-in. mesh was then spread on the surface and then rolled into the No. 2 course

---

**Engineering-Contracting*, Oct. 7, 1908.

to fill up the voids and to provide a smooth surface. The work was carried on only when the broken stone was dry.

The stone was granite and hornblende schist. The work was done in May.

Tar from the Providence Gas Works, and having a specific gravity of 1.25, was used, and its cost delivered on the road was:

	Per bbl.
52 gals. tar	$2.75
Freight, 26 miles	0.62
Haul, averaging 2,000 ft	0.13
Barrel	0.75
Total	$4.25
Deducting rebate of $0.75 per bbl. and adding return freight of $0.19, net deduction	0.55
52 gals., at 7.4 cts	$3.70

About the same number of square yards of 6-in. tar-macadam road was built per 10 hr. day as is built of ordinary macadam, namely, 233 sq. yds., using a 10-ton steam roller and the ordinary macadam gang with the following extra men:

	Per day.
2 tar men, at $1.75	$3.50
3 laborers mixing and placing, at $1.50	4.50
Total extra labor, 233 sq. yds., at 3.5 cts	$8.00

Therefore, the added cost of this 6-in. tar macadam over ordinary 6-in. macadam was as follows:

	Per sq. yd.
Extra labor (as above given)	$0.035
Fuel for melting tar and interest and depreciation of tools	0.005
1¼ gals. tar, at 7.4 cts., delivered	0.093
Total	$0.133
Deduct saving of water cart for sprinkling ($4 per day)	0.013
Net increased cost due to use of tar	$0.120

On another stretch of road built the previous year, 1.15 gals. of tar were used per sq. yd., but the cost per gallon was greater due to the fact that the barrels were not returned. The tar in that case was hauled 6½ miles at a cost of 50 cts. per bbl. of tar for hauling.

The difference in cost of the tar-macadam without the tar on the No. 1 course and with that tar (about 1/5 gal. per square yard) spread on the No. 1 course, was not appreciable. It is believed that the painting of the No. 1 course with tar is not necessary. In common with all methods of construction, with the single exception of the Gladwell system, it is necessary, in order to secure a maximum penetration of the broken stone by the tar, and adequate incorporation of the tar in the macadam, to allow the No. 2 course to remain without rolling and sanding for from 1 to 3 days, depending on the climatic conditions. It was found to be inadvisable to roll the tarred surface during the warm part of the day, as there was a tendency for the No. 2 course to shift if the tar was soft.

Tarvia-macadam constructed by the mixing method appeared to be a fac-simile of the tar-macadam made with tar distilled for 3 hours on the road. It is believed that it is primarily a question of economics whether it is preferable to take gas-house coal-tar direct from the work and distill it on the road, or purchase distilled coal-tar, in the form of Tarvia, for example. It should be borne in mind, also, that tar distilled at permanent works will give a more uniform product.

By the Grouting Method.—The macadam was constructed by spreading 6 ins. of clean, dry No. 1 rock on the rolled subgrade and rolling the same to 4 ins. On the No. 1 course was then spread 2½ to 3 ins. of clean, dry No. 2 rock, which was lightly rolled. The tar, which had been heated in the regular tar kettles, was next poured on the surface of the No. 2 course and allowed to penetrate. The depth of penetration varied from 1 to 2½ ins., depending on the size of the stone comprising the upper course and the amount of rolling the surface had received. Trap rock chip screenings were then spread to a depth of ½ to ¾ in. and thoroughly rolled.

In the construction of the tar-macadam by the grouting or penetration method, the tar was spread over the surface by dippers. This method was very unsatisfactory, an unequal application being the result. In order to procure an efficient road, more tar was applied in patching, the original application of 1.25 gallons being thus increased to 1.87 gallons. If this method is to be used, pouring pots with fan-shaped spouts, or a fan-nozzle connected with a hose from a tank-wagon, should be used, or preferably a spreading machine similar to the Laissailly or Aitken. Even with a machine of the most approved type, and with the stone heated either before or after deposition, it is doubtful if the tar-macadam surface thus constructed would be as uniformly bound together as when laid by the mixing method. The average rate of progress tarring this section was 389 sq. yds. per day, with two tar men and one common laborer. The cost was as follows:

	Per sq. yd.
1.87 gals. tar delivered, at 7.4 cts.	$0.138
Labor (2 tar men and 1 laborer)	0.013
Fuel and plant interest, etc.	0.005
Total	$0.156
Deduct saving water sprinkling	0.013
Total extra cost	$0.143

This 14.3 cts. per sq. yd. is to be added to the cost of ordinary 6-in. macadam.

The grouting method is particularly applicable to the resurfacing of old macadam, which can first be loosened to a depth of 3 or 4 ins., with a scarifier (at a cost of 0.7 ct. per sq. yd.) and then grouted with about 1¼ gals. per sq. yd. and rolled.

By the Gladwell System.—In the construction of tar-macadam by the Gladwell system, the bituminous mastic, consisting of tar and stone chips varying in size from ⅛ to ½ in. in their longest

dimensions, was mixed in a regular mortar box. This mixture was spread to a depth of ¾ in. on the No. 1 course of stone, and the No. 2 course of broken stone was then laid upon it. A coating of tar was spread on the surface, and, after screenings had been applied, the section was thoroughly rolled with a steam roller. The upward penetration of the tar was not measurable, and the surface coat did not penetrate more than 1½ in. In order to procure satisfactory results, it will be necessary to have the No. 1 course so thoroughly compacted as to hold a semi-fluid mixture; the stone composing the No. 2 course should be larger than that generally used, and should be well heated, and, finally, it will be necessary to use a light asphalt roller in order to draw the fluid mixture gradually to the surface, and not attempt to crush the No. 2 course into the binder. Under no circumstances is it believed that the method will prove as efficacious or economical as either the mixing or penetration methods of construction. The rate of progress of this class of work was slow, and would average 156 sq. yds. per day. The labor item was high, two tar men and four common laborers being required, making the labor cost $0.06 per square yard. The tar, 1 gallon per square yard in the mastic and 1.25 gallons on the surface, cost $0.167 per square yard. Summarizing we have the following cost:

	Per sq. yd.
2.25 gals. tar, at 7.4 cts.	$0.167
Labor (2 tar men and 4 laborers)	0.061
Fuel and plant interest, etc.	0.005
Total	$0.233
Deduct saving water sprinkling	0.013
Total extra cost	$0.220

This 22 cts. per sq. yd. must be added to the cost of ordinary 6-in. macadam.

Cost of Tar Macadam, Duluth, Minn.—Mr. E. K. Coe gives the following: Duluth began laying tar macadam in 1902, and it increased so rapidly in popularity that 90% of the total pavement laid in 1906 was tar macadam (71,500 sq. yds.). The pavement is 8 ins. thick, consisting of a tar grouted macadam base 6 ins. thick, covered with 2 ins. of tar macadam that has been mixed in a machine. This 6-in. base is composed of crushed rock ¼ to 2½-in. in size, and is rolled with a steam roller. Then hot tar is spread over the base, 1 gal. per sq. yd., by means of large sprinkling cans, the spout of the can being flared and measuring ½x8 ins. This tar is drawn from a tank wagon, and is spread immediately in advance of the spreading of the 2-in. wearing coat of tar macadam (or tar concrete). This wearing coat is mixed in a portable mixing plant owned by the city. The plant has a capacity of 1,000 sq. yds. of 2-in. wearing coat per day; its shipping weight is 18 tons and it is easily hauled to any part of the city by a steam roller. The plant was built by the Toledo Construction & Supply Co. of Detroit, and cost the city $10,300. It is rented to

the contractors at $20 a day, straight time, the city furnishing the engineman. As many as 1,300 sq. yds. of 2-in. wearing coat have been mixed by this plant in a day.

The stone for the wearing coat is first heated in this plant to 175° to 200° F., which is the same temperature that the tar receives.

The stone is graded in size to reduce the voids to about 7%. When the voids are filled, however, and the stone coated with tar, the particles of stone are separated, so that 11% by bulk of tar is necessary. The following is one of the successful batches:

344	lbs.	stone passing 1¼-in. screen and caught on 1-in.
152	lbs.	stone passing 1-in. screen and caught on ⅝-in.
175	lbs.	stone passing ⅝-in. screen and caught on ⅜-in.
275	lbs.	stone passing ⅜-in. screen and includ. fine dust.
54	lbs.	tar.
1,020	lbs.	total.

Usually 6 or 7 batches of 800 lbs. make a wagonload, bottom dump wagons being used.

Plant foremen are tempted to use an excess of tar, to make a batch appear mixed before it really is, and thus make a bigger day's run.

Tar from the Duluth tar plant is used; it is a by-product of the coke ovens and is very uniform.

The liquid tar for the base is hauled in steel tank wagons, which are provided with small furnaces to keep the tar melted.

The mixed material for the 2-in. wearing coat is dumped from the dump wagons onto a sectional platform, shoveled to place, raked out smooth, and immediately rolled with a 15-ton roller. This course is 2 ins. thick after rolling. When rolled smooth and compact, a flush coat of tar (5 lbs. per sq. yd.) is spread, to seal all surface voids. Formerly a "squeegee" (like a rubber window cleaner) was used for this flush coat spreading, but it was found preferable to use a special cart mounted on two small wheels and with a box 18 ins. square x 12 ins. deep. Behind the cart is a piece of heavy rubber belting set on edge, 8 ins. wide and 3 ft. long, bent to an arc of 60°. Some 7 gals. of fluid tar are poured into the box, in the bottom of which is a 1-in. hole, with a tapering iron plug which is operated by a lever from the drawbar, so that the man who draws the cart can manipulate the plug and deliver a small amount of tar directly in front of the rubber belt, or "squeegee."

Finally the surface is covered with a thin layer of hot rock, beech nut size, and rolled.

The following are the materials required per sq. yd. of 2-in. wearing coat and 6-in. base: 0.3 cu. yd. crushed rock and screenings and 3 to 3½ gals. tar, including waste.

The average contract price in 1906 was $1.23 per sq. yd., which includes everything but grading, and includes a 5-yr. guarantee.

The gang required to mix and lay the 2-in. wearing coat is as follows:

Plant Force:

1 foreman.
1 engineman.
1 fireman.
1 mixer man.
1 weigh man.
1 feeder.
3 to 6 shovelers (according to location of pile of stone).
2 teams hauling tar.
1 watchman.

Street Force:

1 foreman.
3 men spreading tar binder on base.
8 shovelers.
3 rakers.
1 engineman on steam roller.
1 tar heater.
1 man on squeegee cart.
2 men spreading surface screenings.
1 watchman.
1 water boy.
3 to 6 teams according to length of haul.

Cost of Asphalt Macadam, Redlands, Calif.—Mr. C. C. Brown gives the following: During 1906, the city of Redlands, Calif., built 6 miles (100,000 sq. yds.) of asphalt macadam at a cost of 60 cts. per sq. yd., by contract. The city owns a crushing plant, and sells the rock to the contractor at $1 per ton, f. o. b. cars. It is hauled 5 miles by rail. It requires 1¼ cu. yds. of crushed rock (measured in the cars after the 5-mile haul) to make 1 cu. yd. of the finished pavement, including the sand and the asphalt.

The crushed granite is spread in two layers, the bottom layer composed of stones 1½ to 3 ins. in size, the top layer, ¾ to 1½ ins. It is then filled with granite screenings. Each course is rolled, water being freely used while the screenings are being rolled in. As soon as the water dries out, heavy asphaltic oil (75% asphalt) at a temperature of 150° F.; is sprinkled over the macadam, about 2 gals. per sq. yd., or even more. Excavations of the macadam show that the oil has penetrated ½ to ⅔ the way down. The street is then thrown open, and several weeks of traffic iron it out into a smooth pavement. If any ruts appear broken stone (½ to 1 in.) is placed on the macadam and covered with the asphaltic oil.

The asphaltic oil, or liquid asphalt, is applied from a tank wagon hauled by 4 horses. The tank is equipped with a "Glover oiler" (now known as a petrolithic oiler, made by the Petrolithic Pavement Co. of Los Angeles, Calif.). The "oiler," or "distributor," is a cylinder having a series of openings, "the flow being nicely controlled by a set of levers manipulated by a man on the wagon, who regulates the flow according to the speed of the team."

Four tanks, of 800 gals. each, or 3,200 gals., are distributed per day of 8 hrs., when the haul is two miles each way. The heating is done at the unloading tank by steam, which is also used to facilitate unloading the tank car.

The oil costs $1 per 40-gal. barrel, including the freight, which is 33 cts. per bbl.

Cost of Petrolithic Macadam.—Mr. J. C. Black, in an article in the California Journal of Technology, Oct. 8, 1908 (reprinted in *Engineering-Contracting*, Nov. 11, 1908), gave the following: I have inserted an illustration of the rolling tamper and the gang plow, and have assumed wages and prices.

Petrolithic pavement originated in southern California some eight years ago, and since that time has given such great satisfaction that it is now to be found in many parts of the United States, and is even securing a foothold in foreign countries.

Petrolithic pavement consists of a compacted mass of earth, crushed rock or gravel and asphaltic oil, although, since the lighter oils in which asphaltum is dissolved do not remain permanently in the pavement, but disappear (mainly by evaporation) within a few months after its completion, we may properly call it a mixture of earth, rock and asphalt. The rock is intended to act as a wearing coat, and hence is kept mainly near the surface. However, it is not the composition, but the manner in which it is treated, that constitutes the most important and characteristic feature of a petrolithic pavement, for this is the only method in which the entire material of the street is *tamped* into a compact mass of uniform density.

After the road has been brought approximately to grade and is properly crowned, the surface is broken to a depth of 6 to 9 ins., by plowing or otherwise, and then pulverized by farm cultivators and harrows or other machinery. The application of water, often in quantities amounting to several gallons to the square yard of surface covered, usually greatly expedites the pulverization.

After the ground is reduced to a sufficiently fine condition, oil is applied at the rate of three-fourths of one gallon to each square yard of surface and is cultivated in. Another application of oil equal to the first is then made and cultivated, after which the ground is plowed 6 ins. deep, a gang plow, Fig. 6, generally being most satisfactory for this work. The plowing should be such as will thoroughly turn the furrow, and it will generally bring to the surface a small amount of soil which has been untouched by the oil. A slight amount of cultivating or harrowing serves to work out the ridges left by the plow, and the third application of oil, amounting to one gallon to the yard, is then made and cultivated in.

After this it is advisable to put on the road grader, and it is the writer's experience that a liberal use of it is effort well spent. It will be observed that up to the present stage all the work on the road has been done along longitudinal lines—applying the oil and plowing must of necessity be so carried on, and while cultivating

and harrowing may be done zig-zag fashion, it is generally more satisfactory to work in a straight line. While this work results in a fairly uniform mixture of soil and oil, there is a certain tendency toward the formation of streaks, and it is in the correction of this that the great benefit of the road grader as a mixing device

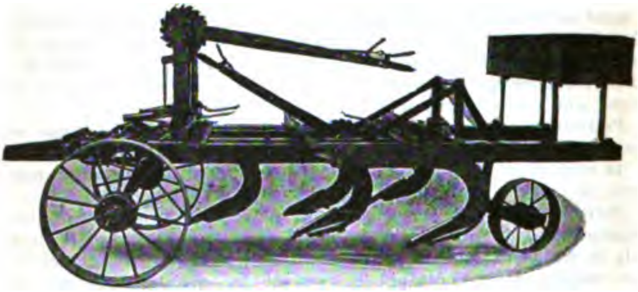


Fig. 6. Petrolithic Gang Plow.

becomes apparent. The soil is in a very loose and finely divided condition, so that with the grader blade set at an angle, a deep cut may be made, and by thus shifting the material from side to side a number of times, the streaks may be entirely removed.

The road is now brought back to grade, and a petrolithic rolling tamper, Fig. 7, is set to work. This tamper consists of a roller

Fig. 7. Petrolithic Rolling Tamper.

about 3 ft. in diameter, the surface of which is studded with iron teeth or feet 9 ins. long and terminating in a slightly rounded surface of about 4 sq. ins. area. The total weight of the machine is between 4,800 lbs. and 5,000 lbs., and as there are 10 or 11 ft. in a row, the weight on each is approximately 450 lbs., or over 100 lbs. to the square inch of surface. The device is patented, and is for sale by the Petrolithic Pavement Co. of Los Angeles. It is drawn

by four horses, from four to six being required, according to conditions. As it passes over the loose material of the street, the feet sink to a depth of 6 or 8 ins., and being flat ended each one leaves a small, compact mass of earth and oil at the place it struck. In order to secure uniform results and prevent the too rapid tamping, a cultivator must be used in connection with the tamper. The cultivator should be adjusted at first to work to approximately the same depth as the tamper, but after two or three trips over the ground, should be raised a notch. After this it should be raised from time to time, but never more than a single notch at a setting, and care should always be taken to avoid too great haste and consequent imperfect tamping. It will be observed that this process builds the pavement "from the bottom up," so to speak, thereby producing a dense mass for the full thickness.

When the road has been tamped so that 2 or 3 ins. of loose material remain on the surface, the tamper should be taken off and the surface smoothed with a road grader or drag. After this, a 2 or 3-in. layer of 1½-in. gravel or crushed rock should be spread upon the road and cultivated so as to mix it with the earth. The rock may be spread by hand, in which case dumping should begin at the end of the road where the wagons arrive, so that they may travel over it instead of over the loose earth, or it may be dumped in a single line down the center of the road, and then spread with the grader. In point of cost, one method offers little advantage over the others. The hand spreading usually gives more uniform results.

After the rock is spread and cultivated, the last coat of oil, amounting to one gallon to the square yard, is applied, and the ground again cultivated. It should then be plowed as deeply as possible without disturbing the tamping already done. A few trips of the cultivator will smooth out the surface, and the tamper may again be set to work. When only a small amount of loose material (say an inch) remains, the cultivator may be taken off altogether, and the surface given a light treatment with a grader or drag before the tamper finishes its work.

A smooth roller will improve the appearance of the newly completed road, but will add little to its efficiency or durability.

The use of water from time to time during the work is a necessity, but because of varying conditions of weather and variety of soils, fixed rules for its use are impossible. In general it will be found that sandy soils must be kept wet from start to finish of work, while clay or adobe requires comparatively little water, and that mainly during the tamping process. If too much water is used on soil of this nature, the almost inevitable result will be clogging of machinery and consequent delays. For applying water, the oil wagons will be found entirely satisfactory.

It is needless to remark that the details of building a petrolithic pavement may be varied considerably, and that good results can be obtained in several ways. In fact, as in many other lines, there are no two pieces of work which can be conducted in exactly the same

manner. Some of those who have been most successful with this form of construction prefer to put the rock on the road before any tamping has been done. This is cultivated, and after the final coat of oil has been applied is plowed under. It might be thought that this would result in the rock being distributed through so great a thickness of soil that its value as a wearing surface would be lost, but the fact is that even when plowed under as much as 6 ins. the cultivation rapidly brings it to the top. If it is attempted to mix it with too small a quantity of soil, a large amount of rock will remain loose on tne surface, and must be removed entirely from the street.

Most of the older petrolithic roads of southern California were built without the use of any rock or gravel, and the satisfaction they have given proves that where the price of rock is high and the keeping down of expenses imperative an excellent pavement may be built of nothing but the natural material of the street mixed with oil.

As to the character of soil in which petrolithic pavement may successfully be built, almost anything will do, provided it is free from a large amount of alkali or other ingredient which will cause decomposition of the oil. In sand the adhesive qualities of the oil will hold the particles together and make possible a good road, where otherwise some expensive paving material would be necessary. No soil gives better results than adobe (clay), although it is hard to work, and consequently may slightly increase the cost. Between the extremes of sand and adobe equal satisfaction will be found.

The greater the amount of asphalt in the oil, the better, and the specifications of the city of Los Angeles require a minimum of 70 per cent. Natural oils having this amount of asphalt are difficult to obtain, but the Sunset District produces some which run from 75 to 80 per cent or even more. These are used exclusively for road oils, and can generally be had at a reasonable price, say 50 cts. per bbl. of 42 gals. Refinery products or residuums are frequently used, and these prove satisfactory when the quality of the asphalt contained in them is unimpaired. The objection to their use arises from the fact that an overheated or burned asphalt lacks the adhesive qualities necessary in a good road oil. A special and expensive test is necessary to determine whether overheating has taken place, and as it should be applied to every carload, besides causing delay, it will form quite an item of expense. Care should be taken to get an oil comparatively free from water and sediment, many specifications requiring the rejection of all oil containing more than 2 per cent of such foreign matter.

It is commonly required that the oil be applied to the road at a temperature of not less than 150° F., and some oils, because of their viscosity, cannot be easily handled at a lower temperature. Although there are still some advocates of the use of cold oil, the general opinion is "the hotter the better."

For heating the oil a portable boiler of some sort is generally

used. The oil may be heated in the cars in which it is delivered, which are usually equipped with steam pipes for this purpose, or it may be run into a tank or pit in which a steam coil has been set. In soil of a clayey nature, a pit without lining may be used, as the oil will penetrate the ground only a few inches. An oil pump with the necessary valves and connections for unloading from car and loading into wagons, will complete the heating establishment.

Oil tank wagons are built of various capacities, the common sizes holding from 800 to 1,000 gals. The distributors, of which there are several good designs, are attached to the rear of the tank, and spread the oil for a width of 6 or 7 ft. Some are divided into three or four sections, so that a narrower strip may be covered if desired. The oil holds its heat well, and if conditions demand, the heating plant may be situated several miles from the work and still allow of the delivery of oil at the required temperature.

Warm weather is desirable for carrying on the work, as when it is cold the oil tends to drag or form into chunks, with resulting irregularities and soft spots in the finished roadway. The road may be opened for traffic as soon as the tamping is finished.

A complete outfit for building petrolithic pavement will be about as follows, though, of course, the magnitude of the work will determine the number of pieces of machinery necessary. It is often possible to rent a portion of the plant, and some cities have their own outfits, which they are prepared to rent to contractors, generally at so much a block:

1 portable steam boiler, with fittings.
1 oil pump and connections.
1 pit or tank of not less than 10,000 gals. capacity, and fitted with steam heating coils.
1 oil wagon and distributor.
1 road grader.
1 road drag (home made).
3 dump wagons, for rock.
1 rooter plow.
1 gang plow.
3 cultivators.
2 rolling tampers.

The operating gang is as follows:

1 foreman.
1 grader man and oil wagon operator.
1 fireman.
7 teamsters.
3 laborers.
35 horses or mules.

The accompanying figures give an average of the amount of labor and material per sq. yd. on several streets, all of which were in clay or adobe soil. In sandy soil more tamping and more water are required, but the preliminary work is much easier. The amount of work necessary varies widely, and depends entirely on local conditions, but by substituting rates of wages and costs of materials

in this table an approximation to the cost of doing the work may be obtained. Proper allowance must, of course, be made for interest and depreciation or for rental of plant.

	Per sq. yd.
Plowing and Pulverizing:	
0.004 hr. rooter plow, 6 horses and driver, at $0.80	$0.0032
0.004 hr. cultivator, 4 horses and driver, at $0.60	0.0016
0.002 hr. tamper, 6 horses and driver, at $0.80	0.0016
Oiling:	
0.0018 hr. fireman, heating oil, at $0.20	0.0036
0.007 hr. oil wagon, 6 horses and driver, at $0.80	0.0056
0.004 hr. oil wagon operator, at $0.20	0.0008
0.0015 hr. hand labor, at $0.20	0.0003
Mixing Oil and Soil:	
0.0015 hr. rooter plow, 6 horses and driver, $0.80	0.0012
0.0027 hr. gang plow, 4 horses and driver, at $0.60	0.0016
0.022 hr. cultivator, 4 horses and driver, at $0.60	0.0132
0.007 hr. hand labor, at $0.20	0.0014
Watering:	
0.005 hr. water wagon, 6 horses and driver, at $0.80	0.0040
Handling and Hauling Crushed Rock:	
0.042 hr. labor, loading into wagons, at $0.20	0.0084
0.056 hr. wagon hauling, 2 horses and driver, at $0.40	0.0224
0.009 hr. labor, spreading rock, at $0.20	0.0018
Grading:	
0.005 hr. road machine, 6 horses and driver, at $0.80	0.0040
0.005 hr. man operating machine, at $0.20	0.0010
0.001 hr. road drag, 4 horses and driver, at $0.60	0.0006
Tamping:	
0.023 hr. rolling tamper, 6 horses and driver, at $0.80	0.0184
0.011 hr. cultivator, 4 horses and driver, at $0.60	0.0066
Smooth Rolling:	
0.003 hr. roller, 6 horses and driver, at $0.80	0.0024
Miscellaneous:	
0.009 hr. labor removing large stones, etc., at $0.20	0.0018
0.0015 hr. wagon, 2 horses and driver, at $0.40	0.0006
Superintendence:	
0.019 hr. foreman, at $0.40	0.0076
Total labor	$0.1137
Materials:	
3.50 gals. asphaltic oil, at $0.02	$0.0700
0.09 gals. oil for fuel (heating), at $0.02	0.0018
5.50 gals. water for sprinkling, at $0.0002	0.0011
0.083 cu. yds. crushed rock, at $1.00	0.0083
Grand total, labor and materials	$0.1949

It will be noted that the three items of loosening the soil and recompacting it with the rolling tamper total as follows:

	Per sq yd.
Pulverizing the soil	$0.0064
Grading	0.0056
Tamping (excluding cultivating)	0.0184
Total	$0.0304

This cost of 3 cts per sq. yd. shows what it would cost to break up, shape with a road machine and tamp the subgrade of a road or street with a rolling tamper, preparatory to laying any sort of pavement. Practically the same price is charged by Massachusetts contractors for "shaping" the subgrade of macadam roads, using

only the old-fashioned and inferior methods. Each rolling tamper compacted 400 sq. yds. per day of 9 hrs.

It will be noticed that the labor item of oiling totals a trifle more than 1 ct. per sq. yd. (0.3 ct. per gal. of oil), excluding the cost of the fuel oil used in heating the other oil, the cost of which is given (under Materials) at 0.18 ct. per sq. yd., making a total of 1.18 cts. per sq. yd. Since 3⅓ gals. of oil were used per sq. yd., this is equivalent to ⅜ ct. per gal. for heating, pumping, hauling and sprinkling the oil on the road.

It will be noted that the crushed rock was spread on to a thickness of 3 ins., measured loose, and that when expressed as a cost per cu. yd. of loose rock instead of per sq. yd., we have the following:

	Per cu. yd.
Loading wagons	$0.108
Hauling	0.269
Spreading	0.022
Total	$0.399

It will be noted that the superintendence cost 17 per cent of the total labor.

It will be noticed that the price assumed for the asphaltic oil (2 cts. per gal.) is low—about one-quarter what it costs in most places outside of California.

None of the foregoing costs include an allowance for interest, depreciation and repairs of plant, nor cost of installing and removing plant.

Cost of Petrolithic Road.—The method of construction was similar to the work just described, except that the broken stone was omitted, and the road was built of the natural soil mixed with asphaltic oil. It was tamped with a petrolithic rolling tamper.

The wages actually paid were as follows per day of 9 hrs.:

Laborer or driver	$2.50
Horse, without driver	1.00
Foreman	3.00

The cost was as follows, excluding installation of plant and interest, depreciation and repairs:

	Cts. per sq yd.
Preliminary team work	0.26
Plowing with rooter plow	0.32
Pulverizing soil	0.34
Sprinkling water	0.27
Leveling with road machine	0.14
Cultivating	0.27
Mixing oil and soil with cultivator	1.06
Sprinkling water	0.20
Tamping with rolling tamper	1.50
Final leveling	0.20
Foreman	0.64
Total labor	5.20
Oil, 3 gals. at 2½ cts. delivered on the road	7.50
Grand total	12.70

It will be noted that the labor items do not include heating and

hauling the oil to the road, for this cost is included in the price of 2½ cts. per gal. paid for the oil. Outside of California it is at present impossible to get asphaltic oil at any such low price.

The soil was a hard clay which required 5 gals. of water per sq. yd. (or about 30 gals. per cu. yd.) to soften the clods so that they could be broken up.

Four horses and a driver operated each rolling tamper, and each tamper compacted 435 sq. yds. per day.

The rooter plow was operated by 6 horses, 2 drivers and 1 man holding the plow. They broke 4,200 sq. yds. per day, and, estimating a depth of 6 ins., the plow loosened 700 cu. yds. daily.

The water was hauled by 6 horses in a wagon holding 840 gals., the wheels of the wagon having tires 5 ins. wide.

A portable oil heater and oil pump loaded the oil from tank cars into 1,000-gal. tank wagons, requiring 20 mins. to load a wagon.

Cost of Telford Roads, New Jersey.—A telford road consists of a "bottoming," 6 to 12 ins. thick, made of rough stone blocks supporting a macadam surface 3 to 6 ins. thick. If the stone for the "bottoming" is limestone or sandstone that comes out in thin layers, readily shaped with a hammer into rectangular blocks, the "bottoming" is laid like a rough stone block pavement. But if the stone is a granite or trap that breaks out in irregular chunks, or if cobblestones are used, no attempt is made to lay a rough block pavement; and the "bottoming" then becomes a sort of macadam itself, consisting of large and small pieces. This last type of telford is the kind so largely used in the towns of northern New Jersey where trap rock is available.

The typical New Jersey telford is made of a "bottoming" 6 ins. thick, consisting of chunks of trap rock broken with hammers after delivery on the road until no chunk is more than 6 ins. thick. The spalls are packed in between the larger stone, and earth is shoveled over the stone from the side of the road until few stones are visible. Then a 5,500-lb. horse-roller is run over the stone before the 3-in. macadam is placed upon it. The macadam is bound with earth, and finally a thin layer of screenings is placed over all—more for appearance sake than for usefulness. The cost of quarrying the trap rock for the "bottoming" and the cost of crushing the portion of it that is used for the macadam surface, will be found in the section on Rock Excavation.

In building a telford pavement on a New Jersey village street, the pavement was made 16 ft. wide. The stones for the bottoming were dumped from wagons, and a gang of 6 men broke the larger ones and placed them all by hand carefully so as to secure a compact "bottoming" 6 ins. thick. This gang of 6 men averaged 4 cu. yds. of bottoming laid per man per 10-hr. day, at a cost of 40 cts. per cu. yd. for placing the "bottoming" after delivery. It took 1.2 cu. yds. of loose stones measured in the wagon to make 1 cu. yd. of "bottoming."

The macadam surface would have cost as much as any other macadam of equal thickness (3 ins.) had it not been for the use of earth as a binder instead of screenings. It took 1.2 cu. yds. of broken stone to make 1 cu. yd. of rolled stone, for a horse roller was used, and it did not compact the stone as much as a steam roller would. The cost of this broken stone can be estimated by data already given. The cost of rolling the "bottoming" and the macadam surface were not kept separately; but rolling both was as follows:

The 2½-ton roller, drawn by a team, averaged 150 lin. ft. of roadway 16 ft. wide per day of 10 hrs., which is equivalent to 90 sq. yds. per day, at a cost of 4 cts. per sq. yd. By far the greater part of the rolling was confined to the 3-in. macadam. The team on the roller was taken off from time to time and hitched to a sprinkling cart. Water for sprinkling the macadam was obtained from a nearby hydrant. Summarizing the costs, we have the following:

Cost of bottoming (6 ins. thick).	Per cu. yd. in place.
Quarrying and loading 1.2 cu. yds. at 40 cts.	$0.48
Hauling 2 miles, 1.2 cu. yds. at 40 cts.	0.48
Placing	0.40
Total per cu. yd. in place	$1.36
Cost of macadam surface (3 ins. thick).	
Quarrying and crushing 1.2 cu. yds. at 55 cts.	$0.66
Hauling 2 miles, 1.2 cu. yds. at 40 cts.	0.48
Spreading 1.2 cu. yds. at 12 cts.	0.14
Shoveling on earth for binder, 0.4 cu. yds. at 12 cts.	0.05
Sprinkling and rolling, 4 cts. per sq. yd.	0.48
Total per cu. yd. in place	$1.81

The cost per square yard, exclusive of grading the roadway, was:

	Per sq. yd.
1-6 cu. yd. bottoming, at $1.36	$0.23
1-12 cu. yd. macadam, at $1.81	0.15
Total	$0.38

Laborers were paid 15 cts. per hr., and teams 35 cts. per hr. The cost of foremen is not included. The cost of the quarrying is given on page 210.

The foregoing relates to trap rock. If limestone or sandstone occurring in thin beds is quarried by wedging, and is roughly scabbled and laid like a paving, the cost of a telford "bottoming" is practically the same as for the slope-wall paving given in section on Masonry. The cost of the macadam surface may be estimated from data given on previous pages.

Cost of Sand-Clay Roads.*—The mixing of sand and clay as a

*Engineering-Contracting, Nov. 28, 1906.

form of road construction has received careful study by the Office of Public Roads, U. S. Department of Agriculture, and a bulletin by William L. Spoon, Road Expert, Office of Public Roads, has recently been issued descriptive of this method of construction. The matter of sand-clay roads is of considerable importance to the Atlantic and Gulf States, where throughout large areas sand and clay are practically the only materials available for road building. In the Southern States a number of sand-clay roads have been built, and they have proved well adapted for light traffic.

The best sand-clay road is one in which the wearing surface is composed of grains of sand in contact in such a way that the voids between the grains are entirely filled with clay, which acts as a binder. Any excess of clay above the amount necessary to fill the voids in the sand is detrimental. All the experiments made by the Office of Public Roads indicate that the materials should not be mixed in a dry state, but should be thoroughly mixed and puddled with water. This is most easily brought about immediately after a heavy rain, the clay having been previously spread and the larger lumps broken up as completely as possible. The surface should then be covered with a few inches of sand and plowed and harrowed thoroughly by means of a turning plow and a cutaway or disc harrow. In cases where the plowing and harrowing are considered too expensive, the mixing may be left to traffic. This, however, leads to a muddy road surface for a long time, although finally it is possible, by a proper distribution of sand upon the clay, to bring about a fairly good result.

Where a slaking clay is used, very much less puddling is required, as there are practically no lumps to be broken up and the mixing can easily be done with the harrow after a rain. Slaking clays do not usually make as effective binders as the more plastic clays, and as a result the road surface becomes more dusty in dry weather. The best kind of clay for this kind of construction is one that slakes sufficiently easily to enable the lumps to be readily broken up, and that at the same time, without being too plastic, has sufficient binding power to cement the grains of sand and form a smooth, impervious surface on the road.

No exact rules can be laid down for calculating in advance the best mixture of clay and sand. An easy method for making a rough estimate of the volume of the clay filler required for any unit quantity of a given sand is given by Mr. Spoon as follows: Two ordinary glass tumblers of as nearly as possible the same size are filled to the brim, one with the dry sand to be tested and the other with water. The water is then poured carefully from the one glass into the sand in the other until it reaches the point of overflowing. The volume of water removed from the glass which was originally full of water can be taken as an approximate measure of the voids in the unit volume of sand contained in the tumbler. A simple calculation will reduce this to percentage volume.

In the construction of sand-clay roads two distinct conditions are likely to be met: The road may have a sandy subsoil, that must be overcome by the addition of clay; or the subsoil may be of clay, and in this case sand must be added to it.

Sand-Clay Construction in a Sandy Subsoil.—In the construction of a sand-clay road upon a sandy subsoil, after the drainage has been provided, the roadbed should be brought to crown. A section of the road nearest the source of the clay is crowned first, and on this section the first load of clay is dumped, each succeeding load being hauled over the preceding, care being taken, however, to spread each dumped load separately and evenly before it is driven over. After the clay has been spread it is covered with a layer of clean sand, and when the road has been opened to traffic additional sand should be added to keep the surface smooth and prevent the formation of mud. If a narrow, single track roadway is to be built, it has been found best to spread the clay to a width of about 12 ft. and to a depth of 6 to 8 ins. in the center, tapering the layer to a thin edge at the sides. After the clay layer is completed and covered with sand, if the clay is plastic and lumpy, it will probably be necessary to plow and harrow it alternately until the lumps are thoroughly disintegrated, advantage being taken of rains to puddle the road surface with a harrow.

More sand must be added if the surface shows a tendency to "ball" and cake, and if, on the other hand, the surface loosens in dry weather, it is due to an insufficient quantity of clay or because the clay lacks binding power.

A roadway 12 ft. wide, with an average depth of 6 ins. of clay, will require 1 cu. yd. of clay to cover 4½ ft. of road length; or 1,173 cu. yds. of clay will be required for one mile of 12-ft. roadway. Mr. Spoon states that the average load has been found to be about ⅔ to ¾ cu. yd., when the haul is over sand, and 1 cu. yd. when the haul is over a dry clay road.

Sand-Clay Construction on a Clay Subsoil.—As in the first case proper drainage must be provided; the road should then be crowned as nearly as possible to the form desired in the finished road. The road surface should have a slope of at least ½ in. per foot. It is much more important to form first this foundation crown with a clay than with a sandy subsoil.

After the foundation has been prepared, the surface should be plowed and harrowed to a depth of about 4 ins., until it is pulverized as completely as possible. It is then covered with 6 to 8 ins. of clean, angular sand, spread so that the layer is thickest at the center of the road.

The first mixing by plow and harrow is done while the materials are still in a comparatively dry state. After the first mixing has been finished the road is finally puddled with a harrow after a rain. In case excess of clay works to the surface, more sand is applied.

When the mixing and puddling has been completed the road is

shaped while it is still soft enough to be properly finished with a scraper and at the same time stiff enough to pack well under the roller or action of traffic.

Cost of Sand-Clay Construction.—The cost of this form of construction varies with the conditions. The following data, given by Mr. Spoon, are based on the assumption that the clay can be procured within a mile of the road that is to be improved, and that the cost of labor is about $1 per day and teams $3 per day. On those assumptions the cost of constructing a 12-ft. sand-clay road on a sand foundation, covered with clay to an average depth of 6 ins., would be approximately as follows for a distance of one mile:

	Total.
Crowning and shaping road with road machine:	
2 teams at $3, 1 day	$ 6.00
1 operator at $1.50, 1 day	1.50
Loading and Hauling:	
Loosening clay with pick and shoveling into wagons, 1,173.33 cu. yds. at 15 cts.	176.00
Hauling, 1,173.33 cu. yds. at 23 cts.	269.86
Spreading Clay with Road Machine:	
2 teams at $3, 3 days	18.00
1 operator at $1.50, 3 days	4.50
Shoveling Sand on Clay:	
Estimated at ½ ct. per sq. yd.	35.20
Harrowing:	
1 team at $3, 2 days	6.00
Shaping and Dressing with Road Machine:	
2 teams at $3, 2 days	12.00
1 operator at $1.50, 2 days	3.00
Rolling:	
Estimated at ½ ct. per sq. yd.	35.20
Total	$579.26

On this basis the estimated cost per square yard of road surface would be about 8 cts. The cost of building a sand-clay road on a clay foundation would not vary much from the figures given. In fact, the latter form of construction would probably be cheaper.

According to the experience of the Office of Public Roads, the cost of sand-clay construction in the South has been found to range from $200 to $1,200 per mile, in most cases running from $300 to $800.

A sand-clay road constructed under the direction of the Office at Gainesville, Fla., 1 mile in length, 14 ft. wide, and having a 9-in. sand-clay surface, cost $881.25 per mile, or 10 cts. per sq. yd. Another sand-clay road built under the direction of the Office at Tallahassee, Fla., 16 ft. wide and surfaced with about 7 ins. of sand-clay mixture, cost $470 per mile, or about 5 cts. per square yard. In case changes of grade have to be made with consequent cuts and fills, the cost would be proportionately greater than the figures given above.

Cost of a Sand-Clay Road in Iowa.*—During the 1908 session of the road school of the State Highway Commission, a mile of sand-clay road was built to test this form of construction for Iowa. The road selected lies partly within the incorporated limits of Waterloo, and was in such bad condition that there was practically no heavy traffic over it. As soon, however, as the road was completed it took all traffic for farmers living northeast of Waterloo, with satisfactory results during the past year. Some of the actual cost figures on the work were as follows:

Amount of clay handled	2,124 cu. yds.
Total road covered	2,800 lin. ft.
Total road improved	5,880 lin. ft.
Width of sections	18 ft.
Dept of clay in center	18-20 in.
Amount of clay per lin. ft.	.75 cu. yds.
Average cost per yd. in place including clearing, weed cutting and finishing	41.6 cts.
Average haul	4,420 ft.
Average cost per mile at above figures	$1,650

This latter figure would include cost where the entire mile had to be covered with clay, but in the case of the road at Waterloo only about one-half the entire length improved had to be covered. One-quarter was improved by cutting down a clay hill, the clay being used in filling over the sand, and one-quarter being simply shaped with a road machine. The cost per mile under these conditions would be reduced to about $1,000. Labor was paid $2.25 per day and $5 per day was paid for teams and dump wagons.

Cost of Cinder-Clay Road, Iowa.†—Several miles of road have been constructed of soft coal cinders in and near Council Bluffs, Ia. This material was used owing to the lack of stone suitable for macadam, the limestone in that neighborhood being nearly worthless for that purpose, and suitable stone being far distant. The method of constructing these roads as given in a letter to the editors from Mr. W. F. Baker, Supervisor of Pottawattamie County, Iowa, is as follows: "We use about 800 cu. yds. of cinders per mile and this leaves them about 5 ins. thick and 10 ft. wide upon the surface of the road. We then plow the roadbed to a depth of about 5 ins. below the cinders and 10 ft. wide, thus thoroughly mixing the cinders with the dirt,—about one half of each. We then use a blade grader moving this mixture outward from the center to the depth plowed and 10 ft. wide, finding a smooth hard surface that is rolled thoroughly. We then move this mixture back with our grader, spreading it evenly over this hard surface about 2 ins. thick at a time, following each layer with a heavy roller, thus building up till it conforms to the roadbed upon each side, and sloping from the center outward about 1½ ins. to the foot. Cinders cement equally well with hill clay, black soil, or gumbo, but not so well with sandy soil. We have had this system of road in use over

***Engineering-Contracting*, Aug. 18, 1909.
†*Engineering-Contracting*, July 3, 1907.

one year where there has been exceedingly heavy traffic with narrow tires and we believe it is equal in durability to macadam, much easier and more cheaply repaired and costing not to exceed one-tenth as much in this locality. This roadbed is not only exceedingly hard but rough, so rubber tires do not pick it up, and when displaced with shoe corks, it cements again under pressure, while rain has no effect upon it. This form of road leaves a dirt road on each side for the travel in dry weather, which I considered very important. As to the cost, if you were to pay 25 cts. per yard for the cinders, and then haul them from one to two miles to your road, your road when completed would cost not to exceed $500 per mile."

Cost of Burnt Clay Roads.*—In some sections of the country clay is the only available material from which roads can be constructed. This is so in large areas in the South, particularly in the valleys of the Mississippi and its tributaries, where sedimentary clays are found very generally. There is little or no sand in these areas and the clays are of a particularly plastic and sticky variety, making traffic in such localities almost impossible during the wet season. To meet this condition the Office of Public Roads, U. S. Department of Agriculture, has made experiments as to the burning of these clays so as to not only destroy the plastic qualities, but also as far as possible to form hard brick-like lumps which should be capable of sustaining traffic. Following these experiments an experimental road was constructed which is proving highly satisfactory. The construction of this type of road as well as the construction of sand-clay roads, is given in a bulletin by William L. Spoon, Road Expert, Office of Public Roads, which has been recently issued by the U. S. Department of Agriculture. In the preparation of the roadbed for burnt-clay roads, the road is graded to an even width between ditches, and is then plowed up as deeply as possible. Furrows are then dug across the road from ditch to ditch, extending through and beyond the width to be burned. If it is intended to burn 12 ft. of roadway, the transverse furrows should be 16 ft. long, so as to extend 2 ft. on each side of the final width of the roadway. Across the ridges formed between these furrows, which should be about 4 ft. apart, the first course of cordwood is laid longitudinally, so as to form a series of flues in which the firing is started. From 15 to 20 of these flues are fired at one time.

Good sound wood, as dry and well seasoned as possible, is used for fuel. But in addition dry brushwood, bark, old fence rails, ties, coal slack, may be used to advantage with the cordwood. The best and soundest cordwood is selected for the first course, and should be laid so that the pieces will touch, thus forming a floor. Another layer of wood is thrown irregularly across this floor, in crib formation, with spaces left between in which the lumps of clay are piled. This clay should be in coarse lumps, so as to allow a draft for easy combustion.

After the lumps of clay have been heaped upon this floor another

*Engineering-Contracting, Dec. 5, 1906.

course of wood is laid parallel to the first. The third layer is placed in exactly the same manner as the first, and each opening and crack filled with brush, chips, or any other combustible material. The top layer of clay is placed over all and the finer portions of the material heaped over the whole structure. This final layer should be taken from side ditches, and may be lumps of all sizes. It is spread evenly over the top in a layer of not less than 6 to 8 ins. Finally the whole is tamped and rounded off so as to hold the heat as long as possible. If coal slack is available two top layers of wood may be left out and the slack thoroughly mixed with the clay. A careful arrangement of the cordwood cribbing to separate the clay is important.

In the practice of the Office of Public Roads, 15 or 20 flues are prepared ready for firing in one section. However, if a large force of laborers is available, a greater number of flues can be fired at one time. The best results are obtained by firing all the flues of a section simultaneously and maintaining the combustion as evenly as possible.

After the firing is completed not only the portion of clay which forms the top of the kiln, but the ridges between the flues should be burned thoroughly, so as to form a covering of burnt clay 10 to 12 ins. in depth, which, when rolled down and compacted, forms a road surface of from 6 to 8 ins. in thickness. If properly burned, the material should be entirely changed in character, and when it is wet it should have no tendency to form mud. When the material is sufficiently cooled the roadbed should be brought to a high crown before rolling, in order to allow for the compacting of the material. This can best be done with a road grader. After this the rolling should be begun and continued until the roadbed is smooth and hard. The finished crown should have a slope of at least ½ in. to the foot.

The main advantages of burning a road over its entire length are that the cost of transporting clay is avoided and that the subgrade of the road is burned as well as the material above.

In giving the cost of burnt-clay construction Mr. Spoon states that it is, of course, impossible to give the cost of a burnt-clay road which will apply to the same work in all sections of the country. Although this form of construction in the South up to the present time has been successful, it cannot as yet be said to ha e passed the experimental stage. The items of cost of the experimental road 300 ft. long, as constructed at Clarksdale, Miss., are as follows:

30¼ cords of wood, at $1.30 per cord	$39.65
20 loads of bark, chips, etc.	6.00
Labor at $1.25 per day and teams at $3 per day	38.30
Total cost of 300 feet	$83.95
Total cost per mile at this rate	$1,478.40

Since the above road was built numerous sections of burnt-clay road have been constructed in that locality, and up to the present time only favorable reports regarding them have been received.

Cost of Maintaining Earth Roads by Dragging.*—In a recently issued Farmers' Bulletin, Mr. D. Ward King gives some data on the cost of maintenance of earth roads by dragging. He states that the most elaborate form of split log drag will cost but a few dollars for material and labor, while one man and team can operate it successfully under all usual conditions. Mr. King gives the following figures as showing the cost of maintaining ordinary country roads per mile per year without a drag. They were obtained in Kansas by Prof. W. C. Hoad, of the University of Kansas, in 1906, and were taken from the official records of the counties:

Crawford County	$52
Douglas County	38
Franklin County	34
Johnson County	48
Neosho County	40
Saline County	43

The average cost is $42.50 per mile per year, and Mr. King states that it may safely be said that the cost of dragging would be trifling in comparison. In the Report of Highway Commissioner of Maine in 1906 it is stated that the least expense per mile for dragging was about $1.50; the greatest a little over $6; the average expense per mile for 5½ miles a little less than $3. One township in Iowa experimented with the drag on 28 miles of highway for a year. The township paid for the making of the drags and hired men to use them. The total expense, including the original cost of the drags, for the year averaged $2.40 per mile. A neighborhood of farmers in Ray County, Mo., employed one of their number to drag a 5-mile stretch. He received compensation at the rate of $3 per day. When the end of the year came and a settlement was made, the cost for the year was found to be $1.66 per mile. The road is a tough clay. Prof. William Robertson, of the Minnesota Agricultural Station, after a year's experience in dragging a main road made entirely of gumbo without any sand or gravel, and which during the past year has shown no defects either by rutting or development of soft places, fixes the cost of the work at not to exceed $5 per mile.

Cost of Making a Corduroy Road.†—The old-fashioned corduroy road is still used frequently by contractors where it is necessary to cross a swampy piece of ground with a temporary roadway. Such a road is frequently made of split cedar sticks, about as large as fence posts, cut in 8-ft. lengths, and laid in a close row on the ground. Then earth is shoveled onto the sticks to even up the hollows. A good axman can cut down, saw, split and lay the cedar for a corduroy road at the rate of 40 to 50 lin. ft. (2½ to 3 rods) per day. Hence if he receives $2 a day, it costs 4 to 5 cts. per lin. ft. of road, or $200 to $250 per mile. The foregoing is based on some records of work done under the direction of the managing editor of *Engineering-Contracting*.

**Engineering-Contracting*, May 6, 1908.

†*Engineering-Contracting*, Feb. 6, 1907.

Cost of Gravel Roads, Indiana.*—Mr. Chas. C. Huffine, county engineer of Clinton County, Ind., has given us the following data on the construction of gravel roads in that county:

	Per cu. yd.
Cost of gravel at pit	$0.10
Stripping pit	0.05
Hauling	0.30
Dumping and spreading	0.03
Shoveling	0.10
Miscellaneous	0.05
Total	$0.63

As about 1,800 cu. yds. of gravel are required per mile of road, the cost will be $1,134. In addition Mr. Huffine estimates the cost of grading the roadbed at $200 and the cost of bridges and culverts at $200, making the total cost per mile $1,534. The above estimate is for bank gravel. The majority of roads built in Clinton County, however, have been made from gravel taken from wet pits, making an additional expense of 25 cts. per cubic yard for dipping or 10 cts. per cubic yard for pumping water, depending on the method by which the gravel is taken out. This would increase the cost of the road $450 or $180 per mile, respectively. The above are about the average cost of gravel roads in Clinton County for the past five years. The contract prices for these roads have varied from $1,750 to $2,100 per mile. The specifications for the construction of a gravel road in the above county require the roadbed to be graded to a width of 24 ft. and the gravel surfacing to be placed to a width of 9 ft. The gravel is required to be placed 15 ins. deep at the middle and 9 ins. at the side. Common labor in Indiana is paid about 13½ cts. per hour, and about 30 cts. per hour is paid for a two-horse team and driver.

Cost of Gravel Street, Michigan.—Mr. A. W. Saunders gives the following: The gravel was often very wet, puddled in fact; 87 cu. yds. of gravel made 90 lin. ft. of street 6 ins. thick on the center line and 4 ins. thick at the gutter, and 25 ft. wide. The gravel was unloaded from a lighter, 10 men doing the work. Six men in a 10-hr. day loaded 124 cu. yds. on six teams, using eight wagons. Each round trip of team averaged 45 mins. a total of 68 trips being made in a 10-hr. day.

The cost per cubic yard measured loose was as follows:

	Per cu. yd.
Gravel	$0.850
Unloading, at $1.75 per day	.150
Hauling, at $4.50 per day	.257
Spreading, at $1.75 per day	.087
Superintendence and depreciation	.021
Total	$1.365

Cross Reference on Cost of Grading Roads.—The reader is referred to the section on Earth Excavation and Embankment for the discussion of grading costs.

**Engineering-Contracting,* Dec. 18, 1907.

Cost of Grading a Road, New York.—A stiff clay was ditched and graded for a New York state macadam road near Buffalo, at the following cost per cu. yd.:

	Per cu. yd.
Plowing	$0.05
Loading into wagons	0.12½
Hauling 1,000 ft.	0.05½
Spreading	0.05
Foreman, supt., timekeeper and water boy	0.05
Total	$0.33

The work was done by contract, and wages were $1.50 for common laborers, $4.50 for teams, per 8-hr. day. The clay was loosened with a rooter plow and was hauled in patent dump wagons. This cost is a safe figure for stiff material hauled not more than 1,000 ft.

The cost of grading 2½ miles of road under conditions essentially as above, except that the material was a gravelly soil, was 28 cts. per cu. yd.

Cost of Grading a Road, Maryland.—Mr. W. W. Crosby gives the following:

Grading a road for a 6-in. macadam pavement 14 ft. wide, the whole roadbed being 24 ft. wide, cost 39.6 cts. per cu. yd., not including the cost of "shaping," which was ⅓ ct. per sq. yd., which is equivalent to adding 4.2 cts. per cu. yd. to the grading cost. The road averaged 1,700 cu. yds. per mile. Work was done by day labor, negro labor at 10 cts. per hr., and team at 40 cts.

Cost of Grading Road With Road Machine, Michigan.—Mr. Frank F. Rogers gives the following data on work done at Port Huron, Mich.: A street was to be macadamized with a strip of macadam 9 ft. wide and about 5 ins. thick after rolling. The earth was sand and sandy loam overlying clay. The side ditches had already been made, and the street was already well turnpiked (crowned), so that the grading consisted merely in preparing a bed for the macadam and in making earth shoulders to hold the stone. For this purpose a common road machine was used, first to cut off the high places and fill the hollows by setting the blade at right angles with the center line of the street. Then, to form the shoulders and cut the crown of the subgrade, the blade was set at a slight angle so as to crowd enough earth to one side of the 9-ft. strip, forming first one shoulder, then the other. Stakes were set 1 ft. outside the 9-ft. strip to give line in operating the grader. The edges of the shoulders were afterward trimmed by hand with a shovel while the subgrade was being rolled with a steam roller. The grading cost $85 per mile in this soft sandy soil, where no ditching or turnpiking was done.

On another stretch of road, in sand, it was necessary to break up, re-grade, and trim the ditches to line, as well as to make the shoulders for the 9-ft. macadam. This cost about $360 per mile.

Two teams, a driver for each team and another man to operate the grader were used. Each team and driver received $3.50 for 10 hrs. and the other man received $1.50.

Average Prices of Pavements in 100 Representative Cities, Together With the Wages of Labor and Prices of Paving Materials.*— In our issue of March 27,1907, we printed a number of tables showing the character and cost of paving work done in 1906, in a number of representative American cities. In the present issue we present somewhat similar data on the paving work done in 1907 in 100 cities of the United States. No attempt was made to get complete statistics of the United States; the purpose, rather, was to select cities in various sections of the country on the assumption that their practice and activity would represent with approximate accuracy the practice and activity of these sections as a whole.

Perhaps the most interesting of the tables is Table IV, showing the wages of labor and the prices of materials. It will be noted from this that the 8-hr. day does not prevail in all of the cities reporting. Practically all of the Eastern states have an 8-hr. day, while in the Middle West the 10-hr. day seems to be the more common. The rates of wages of labor vary, being lowest in the South and highest in the West. In the New England cities the wages of common labor averaged $2.00 per day, while in the Middle West the average was $1.75. The cost of the various paving materials taken in combination with the cost of labor are interesting in as much as they show in a measure the reason for the variation in the cost of the pavement given in the other tables.

Tables V to X, giving the cost of the various kinds of pavement, should be of general interest, although it is evident that no perfectly just comparison can be made without going far deeper into local conditions than the data sent us would permit. In these tables the average price per square yard includes grading, unless stated otherwise.

Cost of Paving in 50 American Cities.†—Tables XI to XIII show the construction and cost of street paving in about 50 representative American cities. These figures were collected by the Committee on Roads and Pavements of the Illinois Society of Engineers and Surveyors and were reported at the annual convention held last week. The records cover macadam, asphalt and brick and block pavements and give the materials used, thickness and cost. The costs given are, of course, costs to the cities and not costs to the contractors. No very accurate general conclusions can be drawn from these records, and in fact this was not the purpose of their collection; they show individual records of city paving work and for this are deserving of careful study. Mr. A. N. Johnson, State Engineer, Illinois, was chairman of the committee, making the report from which the tables are taken.

**Engineering-Contracting*, April 1, 1908.

†*Engineering-Contracting*, Feb. 3, 1909.

TABLE IV.—PREVAILING WAGES FOR LABOR AND PRICES OF PAVING MATERIALS IN 96 CITIES.

	Working Day Hours.	Common Labor.	Paver.	Team with Driver.	Cement Per bbl.	Broken Stone Per Cu. yd.	Sand Per Cu. yd.	Paving Brick Per M.	Asphalt Per ton.
Albany, N. Y.	8	$1.75	$4.50	$5.00	$1.45[1]	$1.50	$0.25[2]	$23.25[3]	.....
Allentown, Pa.	10	1.50	....	4.25	1.60	1.08[4]	2.03	.....	.....
Ann Arbor, Mich.	9	1.75	....	4.00	2.00	....	.75	21.00	.....
Atchison, Kan.	8	1.50	1.76	3.00	2.30	1.50	.85	11.00	.....
Battle Creek, Mich.	10	2.00	3.50	4.00	.70	....	.10	20.75	.....
Bay City, Mich.	10	1.75	4.00	3.50	1.60	1.25	.90	17.00	28.50
Beaumont, Tex.	9	1.75	4.00	4.50	1.95	1.50	.87	21.00	.....
Binghamton, N. Y.	8	1.75	3.50	3.50	1.60	1.00[5]	1.00	24.00[8]	.....
Bridgeport, Conn.	8	1.75	4.00	5.00	1.80[7]	1.50[7]	1.25[7]	27.00[7]	.....
Brockton, Mass.	8	2.25	....	4.50	....	1.00[6]	.....	.....	.....
Buffalo, N. Y.	8	1.75	3.20	5.00	....	....	.....	.....	.....
Butte, Mont.	8	3.50	6.00	7.00	3.45	1.15	1.00	.....	.....
Cedar Rapids, Ia.	10	1.75	4.00	3.50	2.00	1.35	1.00	20.00	.....
Charlotte, N. C.	10	1.00	....	....	.85	1.10	.70	.....	.....
Cheyenne, Wyo.	8	2.50	....	5.00	3.00	....	.50	.....	.....
Clinton, Ia.	10	2.00	3.00	3.50	1.80	1.50	.60	14.50	.....
Columbus, O.	10	1.85	3.50	4.25	1.60	1.25	1.25	15.00	.....
Council Bluffs, Ia.	10	1.75	2.50	3.50[9]	2.00	2.25	.70	23.00	.....
Dayton, O.	10	1.75	2.25	4.50	1.50	....	.75	17.00	.....
Denison, Tex.	10	1.50	....	....	....	....	....	.....	.....
Detroit, Mich.	8	1.75	2.50	4.50	1.46[10]	.84[11]	.50	19.75[12]	26.70
East Liverpool, O.	9	1.75	3.50	4.50[13]	....	....	.65	8.00	.....
East St. Louis, Ill.	8	1.75	2.50	3.50	1.70	1.10	1.00	16.18	.....
Easton, Pa.	..	.20[14]	....	.50[15]	....	.90[16]	....	.....	.....
East Orange, N. J.	10	1.55	3.50	5.00	1.60	2.14	1.00	.....	.....
Elgin, Ill.	9	2.00	[17]4.00	4.50	1.60	1.35	1.50	20.00	.....
Elizabeth, N. J.	10[18]	1.75	5.00	4.00	1.50[19]	.90	.70	.....	.....
Elmira, N. Y.	8	1.75	5.00	3.50	1.70	1.00	1.25	22.50	35.00
Evanston, Ill.	9	2.00	4.50	5.40	2.15	1.25	1.25	19.00	.....
Fond du Lac, Wis.	..	2.25	2.75	4.00	1.80	.91[20]	1.00[20]	26.00	.....
Fort Wayne, Ind.	10	1.75	2.50	4.00	1.40	1.05	.70	19.00	25.00
Fort Worth, Tex.	9	1.75	2.00	3.50	2.50	1.00[5]	1.50	14.50	.....

[1]Net. [2]At Bank. [3]F. O. B. Albany. [4]Gravel and sand for concrete cost about $.75 per cu. yd. [5]Gravel. [6]Block. [7]Material delivered on the work. [8]Per ton from city crushers; $1.45 purchased. [9]To $4. [10]Natural cement $.61. [11]2 in. per ton. [12]F. o. b. City. [13]To $5. [14]Per hour. [15]Per hour. [16]Per 2,000 lbs. on street. [17]Asphalt paver $3. [18]Eight hours for pavers. [19]To $1.75. [20]F. o. b. cars.

TABLE IV.—PREVAILING WAGES FOR LABOR AND PRICES OF PAVING MATERIALS IN 96 CITIES.—(CONTINUED.)

	Working Day Hours.	Common Labor.	Paver.	Team with Driver.	Cement Per bbl.	Broken Stone Per Cu. yd.	Sand Per Cu. yd.	Paving Brick Per M.	Asphalt Per ton.
Grand Rapids, Mich.	10	2.00	3.00	4.00	2.00	....	.90	22.00	.....
Great Falls, Mont.	8	3.00	....	6.00	3.70	2.00	1.25	.....	.....
Harrisburg, Pa.	10	1.50	3.50	....	....	1.00	....	.....	.....
Haverhill, Mass.	8	2.00	2.25	4.50	....	....	....	.....	.....
Holyoke, Mass.	8	2.00	2.25	4.50	1.85	1.26	.10	26.50	.....
Jamestown, N. Y.	8	1.75	2.50	4.00	1.60	1.50	1.75	14.00	15.00
Kansas City, Kan.	8	1.75	....	4.00	2.00	1.66	1.00	11.00	.....
Keokuk, Ia.	10	1.75	....	3.50	....	1.25[21]	1.00	.....	.....
Knoxville, Tenn.	10	1.50	3.00	5.50	.95[22]	.75	.75	22.00	.....
La Crosse, Wis.	10	2.00	....	4.00	....	....	.50	.....	.....
Lansing, Mich.	10	1.75[23]	....	4.00	1.80	....	....	.....	.....
Lawrence, Mass.	8	2.00	3.00	5.00	2.00	1.93[5]	.77	.....	.....
Marion, Ind.	10	1.50	2.50	4.50	1.85	1.15[7]	.60[7]	19.00	.....
Medford, Mass.	8	2.00	....	....	....	....	....	20.00	.....
Middletown, N. Y.	8	2.00	3.00	4.50	1.50	1.00	.90	27.00	.....
Minneapolis, Minn.	8	2.00	3.25	4.00	1.80	1.75	.80	23.00	.....
Milwaukee, Wis.	10	....	....	4.00[19]	1.75[24]	1.20	....	.....	.....
Moline, Ill.	10	2.00	3.00	4.00	....	1.00	.60	.....	.....
Muncie, Ind.	10	1.50	....	3.25	1.70	1.00[7]	1.00[7]	18.00[12]	.....
Nashville, Tenn.	9	1.25	....	....	2.50	.75	1.50	21.00[20]	.....
New Albany, Ind.	10	1.75	2.00	3.50	....	....	....	.....	.....
New Bedford, Mass.	8	2.00	2.50	4.50	1.60	1.25	1.00	.....	.....
New Brunswick, N. J.	10	1.65	2.50	5.00	1.65	1.25[7]	1.25[7]	27.50[12]	.....
New Castle, Pa.	9	1.75	3.50	4.50	1.58	....	1.50	11.25	.....
Newton, Mass.	8	1.75	....	5.25	1.75	1.33	....	.....	.....
Niagara Falls, N. Y.	8	1.75	4.00	5.20	1.35	1.35	1.10	14.00	.....
North Adams, Mass.	8	1.75	3.50	4.00	1.49	1.00	1.00	30.88	.....
Oshkosh, Wis.	10	2.00	3.00	4.50	....	1.20	1.25	.....	.....
Pittsburg, Pa.	..	1.75	....	5.50	1.65	....	....	.....	.....
Pittsfield, Mass.	8	....	....	4.50	1.65	1.62[20]	.75	.....	.....
Portland, Me.	9	1.75	3.50	5.00	1.84	1.24[25]	.80	25.00	.....
Poughkeepsie, N. Y.	8	1.75	4.00	5.00	1.64	1.34	.90	15.00	.....

[21]At Crusher. [22]Natural Cement. [23]To $2.50. [5]Gravel. [7]Material Delivered on work. [19]To $5. [24]To $2.
[12]F. O. B. City. [20]F. O. B. Cars. [25]Per ton.

TABLE IV.—PREVAILING WAGES FOR LABOR AND PRICES OF PAVING MATERIALS IN 96 CITIES.—(CONCLUDED.)

	Working Day Hours.	Common Labor.	Paver.	Team with Driver.	Cement Per bbl.	Broken Stone Per Cu. yd.	Sand Per Cu. yd.	Paving Brick Per M.	Asphalt Per ton.
Providence, R. I.	9	1.53	2.52	4.05	1.63	1.66	.10	.....	.....
Pueblo, Colo.	8	2.00	3.00	4.00	2.15	.20	.50	15.00	.....
Racine, Wis.	10	2.00	3.00	5.00	2.20	1.35	.75	18.50	.....
Richmond, Ind.	10	1.75	2.50	3.50	2.00	1.00	.75	.....	.....
Rockford, Ill.	8	1.75	....	3.75	....	....	....	.....	.....
Saginaw, Mich.	9	2.00	....	4.50	1.53	1.40	.90	17.00	.....
Salt Lake City, Utah	8	2.25	....	4.50	2.65	1.00	.90	.....	22.00
San Antonio, Tex.	8	1.50	5.00	3.00	16.00[25]	1.35	1.40	19.00	.....
San Diego, Cal.	8	2.00	7.50	5.00	3.00	2.50	1.25	.....	.....
Sandusky, O.	10	2.00	2.50	4.00	1.80	1.25	.50	19.50	.....
San Jose, Cal.	8	2.50	....	5.00	2.25[26]	1.70	1.00	.....	.....
Savannah, Ga.	9	1.50	[27]2.50	3.50	2.00	....	....	28.00	.....
Seattle, Wash.	8	2.25	5.00	6-7	2.80	....	1.00	22.00	20.00
Sedalia, Mo.	10	1.50	3.50	4.00	.65[22]	1.25	1.30	12.50	.....
Sheboygan, Mich.	10	1.75	2.50	4.50	2.65	1.20	.75	27.00	.....
Somerville, Mass.	8	2.00	....	3.50[29]	1.42	1.09[30]	.65[30]	12.50	.....
South Bend, Ind.	10	2.00	....	4.50	1.65	1.40	.90	21.00	30.00
Springfield, Ill.	9	1.75	2.00	3.50	1.50	1.30	1.00	11.00	27.00
Superior, Wis.	10	2.00	3.50	5.00	2.00	1.70	1.00	26.00	.....
St. Louis, Mo.	8	1.75	4.00	4.00	1.35	1.00	1.00	15.00	25.00
Stockton, Cal.	8	2.50	....	5.00	2.00	2.00	.50	.....	.....
Syracuse, N. Y.	8	1.75	3.50	4.00	1.60	1.20	1.00	14.00	35.00
Tacoma, Wash.	8	2.00	6.00	6.00	3.00	.75	.75	21.00	18.00
Toledo, O.	8[31]	1.75	3.00	4.00	1.45	1.00	.95	20.00	30.00
Troy, N. Y.	8	1.50	4.00	5.00	....	1.25	.50	24.00	.....
Vicksburg, Miss.	10	1.50	2.50	4.00	2.60	2.20[5]	1.50	22.00	.....
Walla Walla, Wash.	8	2.50	....	4.50	3.50	2.00	2.00	.....	.....
Washington, D. C.	8	1.50	3.50	4.00	1.80	1.50	.74	22.00	.....
Wilkesbarre, Pa.	10	1.50	3.50	4.00	1.40	.75	1.00	25.20[32]	.....
Williamsport, Pa.	9	1.75	3.00	5.00	1.50	1.15	.65	20.00	.....
Winona, Minn.	10	1.75	2.00	4.00	....	1.25	....	.....	.....

[5]Gravel. [20]F. O. B. Cars. [22]Natural cement. [23]To $2.50. [24]To $2.00. [25]Per ton. [26]For California, $3.75 for imported. [27]To $3. [28]Delivered on dock costs $.60. [29]Average, teams owned by city. [30]Per ton on car. [31]8 to 10. [32]Some of brick cost $19.00.

TABLE V.—AVERAGE PRICE OF BRICK PAVEMENT LAID IN 1907 IN 65 CITIES.

	Sq. Yds.	Av. Price per Sq. Yd. Including Base.	Guarantee, Years.	Price per Cu. Yd. for Grading if Paid Separately.	Total Thickness Pavement, Inches.	Concrete Base: Thickness, Inches.	Concrete Base: Portland or Natural Cement.	Concrete Base: Proportions
Albany, N. Y.	25,883	$2.28[1]	5	.....	11¾[2]	6	P	1-3-6
Ann Arbor, Mich.	409	1.60*	..	$0.25	10	6	P	1-8
Atchison, Kan.	19,891	1.28*	1	.35	9½	.	..	.....
Battle Creek, Mich.	18,712	1.565	24	.....	11	6	N	1-6
Bay City, Mich.	6,456	1.78	1	.....	9	5	P	1-3-5
Bayonne, N. J.	4,800	.....	5	.40	9	5	P	1-3-6
Beaumont, Tex.	9,932	2.06[3]	..	.....	12	6	P	1-3-6
Binghamton, N. Y.	38,195	1.99	10	.....	11	6	P	1-2-5
Bridgeport, Conn.	7,447[4]	2.86	5	.....	12	6	P	1-4-8
Buffalo, N. Y.	34,932	2.67	10	.....	11	6	P	1-10
Cedar Rapids, Ia.	25,308[5]	1.48*	..	.30	12	.	..	.....
Cleveland, O.	406,284	1.35*[6]	3	.40	5	.	..	.....
Clinton, Ia.	1,405[6]	1.74*	1	.45	10	4	P	1-3½-6
Columbus, O.	112,740	1.57*	5	.50	11	6	P	1-4-8
Council Bluffs, Ia.	36,945	1.975	1	.....	9½[7]	4[8]	P	1-3-5
Dayton, O.	78,000	1.68	5	.....	11	6	P	1-3-7
Denison, Tex.	4,473	2.09	..	.55	9½	4	P	1-9
Detroit, Mich.	63,476	2.50	..	.....	..	.	..	.....
East Liverpool, O.	9,763[9]	1.16⅔*	1	.33⅓	..	.	..	.....
East St. Louis, Ill.	82,807	1.60*	1	.25[10]	11½	6	P	1-3-6
Elgin, Ill.	11,112	2.10	5	.....	6	5	P	1-3-6
Elmira, N. Y.	1,686	2.586	5	.....	4	11	P	1-3-6
Evanston, Ill.	12,611	1.73*[25]	5	.25[26]	11¼	5	P	1-3-7
Fond du Lac, Wis.	18,000[11]	2.35*	5	.50	10⅔	6	P	1-3-6
Fort Wayne, Ind.	1,935	1.62*	10	.45	11	6	P	.....
Fort Worth, Tex.	10,000	2.00	..	.50	11	5	P	1-9
Grand Rapids, Mich.	73,685	1.85*	5	.25	11	6	P	1-4-8[12]
Harrisburg, Pa.	709	2.00	5	.....	9	6	P	1-3
Holyoke, Mass.	11,539	2.26	..	.....	10	5	P	1-3-6
Jamestown, N. Y.	10,477	1.64*	5	.40	11	6	P	1-9
Kansas City, Kan.	2,500	1.11	5	.....	..	.	..	.....
Knoxville, Tenn.	7,065	2.17	8	.....	12	6	N	1-2-4
La Crosse, Wis.	3,378	1.865	..	.....	12	6	N	1-1½-4

*Does not include grading.
[1]On concrete base, for gravel base $1.88, and for telford base $2.19. [2]For concrete base; for gravel base total thickness is 13¾; for telford bse thickness is 15¾. [3]Done by city forces. [4]Reese Hammond blocks. [5]Small amount of this pavement was laid on 5 in. concrete base at $1.89 and $1.98 per square yard; greater part was laid on 6 in. of macadam and 2 of sand. [6]From $1.35 to $1.53. [6]In 20 ft. alley. [7]Some 10½ in. and 11½ in. thick. [8]Some of the base is 4 in., 5 in. and 6 in. thick. [9]Laid on 8 in. gravel and 2 in. of sand. [10]$.25 for excavation, $.70 for fill when hauled in. [11]Capitol and Metropolitan brick used. [12]Proportion used natural cement 1-2-4. [25]$1.75 to $2.05. [26]$0.10 to $0.25.

TABLE V.—AVERAGE PRICE OF BRICK PAVEMENT LAID IN 1907 IN 65 CITIES.—(Concluded.)

	Sq. Yds.	Av. Price per Sq. Yd. Including Base.	Guarantee, Years.	Price per Cu. Yd. for Grading if Paid Separately.	Total Thickness Pavement, Inches.	Concrete Base—Thickness, Inches.	Concrete Base—Portland or Natural Cement.	Concrete Base—Proportions
Lansing, Mich.	32,859	1.56[13]	5	.....	..	.	..	.....
Middletown, N. Y.	5,000	2.50	..	.....	12	6	P	1-3-5
Milwaukee, Wis.	51,349	2.15	..	.....	..	.	..	.....
Minneapolis, Minn.	23,760	2.10	..	.....	10	5	P	1-3-6
Moline, Ill.	13,340	1.80	5	.....	10½	5	P	1-3-6
New Albany, Ind.	21,255	1.85	5	.....	..	5	N	1-2-5
New Brunswick, N. J.	19,000	2.41	5	.....	11½	6	P	1-3-6
New Castle, Pa.	.....	1.38*	5	.36	11½	6	P	1-3-8
Niagara Falls, N. Y.	13,218	2.20	10	.....	8½	4	P	1-5-8
Oshkosh, Wis.	21,100	2.00	5	.....	11½	6	P	1-3-7
Pittsburg, Pa.	30,936	1.87*	1	.53	11	6	P	1-3-6
Portland, Me.	250	3.35	..	.....	..	6	P	1-3-6
Poughkeepsie, N. Y.	3,686[14]	1.847	..	.....	10½	2[15]	P	1-2-4
Racine, Wis.	63,978	2.10*	..	.....	..	5	P	1-3-5
Saginaw, Mich.	28,130	1.67*[25]	..	.40	11	6	P	1-3-5
Sandusky, O.	6,900[15]	2.00*	5	.50	11½	6	P	1-3-6
Savannah, Ga.	12,047[16]	1.63	.	.....	..	.	..	.....
Seattle, Wash.	37,119	2.60*	6	.70	9	5[17]	..	.....
Sedalia, Mo.	27,632	1.52	5	.....	10	4	..	.....
Sheboygan, Mich.	2,000	2.00	..	.....	..	6	P	1-3-5
South Bend, Ind.	86,859	1.34½*	..	.30	11	.	..	.....
Springfield, Ill.	59,115	1.67	..	.....	11	6	P	1-3-5
Superior, Wis.	3,112	2.39*	..	.60	9	5	P	1-2½-5
St. Louis, Mo.	196,210	1.80*	5	.....	12	6	P	1-4-7
Syracuse, N. Y.	35,461	1.98*	10	.355	11	6	P	1-3-6
Tacoma, Wash.	1,793[20]	3.10*	..	.....	9[18]	4[19]	P	1-3-6
Toledo, O.	86,775	1.75*[21]	5	.....	..	6	..	.....
Troy, N. Y.	207,749	2.20	5	.....	10	6	P	1-3½-7
Vicksburg, Miss.	36,503	2.25*	10	.625	11½	6	P	1-3-6
Washington, D. C.	13,758[27]	2.50	..	.....	..	.	..	.....
Wilkesbarre, Pa.	11,315[22]	2.04	..	.23	12	6	P	1-2-5
Williamsport, Pa.	2,640	2.00	1	.....	11½	6	P	1-3-7

*Does not include grading. [13]Work complete on gravel base. [14]Day work repaving. Syracuse blocks used. [15]New base 2 in.; old base 5 in. [15]Metropolitan block used. [16]Laid on soil. [17]5 in. to 6 in. base. [18]9 in. and 11 in. thick. [19]4 in. and 6 in. base. [20]Miles. [21]$1.40 per sq. yd. on 6 in. broken stone base. [22]28,098 sq. yds. of pavement was laid on 6 in. crushed stone base at average cost of $1.70 per sq. yd. and 4,952 sq. yds. was laid on a similar base at a cost of $1.60 per sq. yd. [23]Where excavation exceeds 12 in. it is paid for at rate of $.20 per cu. yd. [24]City does own work. [25]$1.75 to $2.05. [26]$1.67 with asphalt filler, $1.40 with cement filler. [27]Alley pavement vitrified block, 3 in. x 4 x 4 in., 44 per yd.

TABLE VI.—AVERAGE PRICE OF ASPHALT PAVEMENT LAID IN 1907 IN 39 CITIES.

	Sq. Yds.	Av. Price per Sq. Yd., Including Base.	Guarantee. Years.	Price per Cu. Yd. for Grading if Paid Separately.	Total Thickness Pavement. Inches.	Concrete Base: Thickness, Inches.	Concrete Base: Portland or Natural Cement.	Concrete Base: Proportions.
Albany, N. Y.	31,605	$2.70	10	.....	8½	6	P	1-3-6
Allentown, Pa.	52,342	1.97	1	.....	6½	4	P	1-3-6
Bayonne, N. J.	4,013	....	10	$0.40	7½	5	P	1-3-6
Buffalo, N. Y.	53,748	2.70[1]	10	.....	9½	6	P	1-10
Buffalo, N. Y.	78,017	1.96[2]	..	.....	...	..	..	.....
Cleveland, O.	21,078	2.25*	10	.40	9	6	P	1-3-6
Columbus, O.	71,700	2.00*	10	.50	9	6	P	1-4-8
Dayton, O.	34,000	2.10	5	.....	9	6	P	1-3-7
Detroit, Mich.	35,392	2.65	10	.....	...	..	..	.....
Elgin, Ill.	10,508	2.10	5	.....	7½	5	P	1-3-6
Elizabeth, N. J.	12,150	2.46	10	.....	9½	6	3	1-2-4[4]
Elmira, N. Y.	8,157	2.325	10	.....	9	6	P	1-3-6
Fond du Lac, Wis.	35,000[5]	2.04*	5	.53	7½	5	P	1-3-6
Fort Wayne, Ind.	61,983	1.90*	10	.45	8½	6	P	1-3-6
Harrisburg, Pa.	148,066	1.70	5	.....	9	6	P	1-3
Jersey City, N. J.	31,579	1.90	5	.40	6½	5	N	1-3-6
Knoxville, Tenn.	44,900	1.98	8	.....	19	6	N[6]	1-2-4
Milwaukee, Wis.	43,939	2.25	5	.....	9	6	P	1-3-6
Moline, Ill.	16,793	1.98	10	.....	8½	5	P	1-3-6
New Albany, Ind.	56,704[5]	1.745	5	.40	8½	6	N	1-2-5
Niagara, Falls, N. Y.	47,804	2.38	10	.....	6½	4	P	.....
Oshkosh, Wis.	26,217	2.25	5	.....	8½	6	P	1-3-7
Pittsburg, Pa.	135,694	1.69*	5	.53	9	6	P	1-3-6
Providence, R. I.	4,786	1.50[7]	..	.....	...	..	..	.....
Pueblo, Colo.	38,651	2.07*	5	.33	9	6	P	1-3-6
Racine, Wis.	16,647	2.09*	5	.....	...	5	..	1-3-6
Saginaw, Mich.	35,308	1.59*	10	.40	8½	6	P	1-3-5
Salt Lake City, Utah	92,000	2.05[8]*	10	.50[9]	9½	6	P	1-3-7
San Diego, Cal.[15]	9,244	1.66	..	.....	8	..	..	.....
Savannah, Ga.	136,717	1.10[3]	5	.....	...	..	..	.....
Seattle, Wash.	84,961	2.10*	10	.70	9	5[10]	P	1-4-7

*Does not include grading.
[1]On the new base. [2]Resurface. [3]Both natural and Portland cement used. [4]Also 1-3-6. [5]Trinidad asphalt.
[6]Specifications for present year will call for Portland cement concrete, 1-3-6 proportions. [7]Wearing surface.
[8]Some at $2.45. [9]Some at $0.77. [10]5-in. and 6-in. [15]2-in. asphalt wearing surface on 6-in. asphalt macadam base.

TABLE VI.—AVERAGE PRICE OF ASPHALT PAVEMENT LAID IN 1907 IN 39 CITIES.—(Concluded.)

	Sq. Yds.	Av. Price per Sq. Yd., Including Base.	Guarantee. Years.	Price per Cu. Yd. for Grading if Paid Separately.	Total Thickness Pavement. Inches.	Concrete Base Thickness, Inches.	Concrete Base Portland or Natural Cement.	Concrete Base Proportions.
South Bend, Ind.	8,884	2.25*	5	.50	8½	6	P	1-9
Springfield, Ill.	24,315	1.86	5	.....	8½	6	P	1-3-5
St. Louis, Mo.	149,945	2.00*	5	.....	9	5	P	1-4-7
Stockton, Cal.	13,500	1.71*	..	.25	8	5	P	1-3-6
Syracuse, N. Y.	16,767	1.92*	10	.35	8½	6	P	1-3-6
Tacoma, Wash.	7,672[11]	2.10*	..	.....	7½[12]	4[13]	P	1-3-6
Toledo, O.	19,416	1.60[3]	..	.....	...	..	..	.....
Troy, N. Y.	11,513[14]	3.37	5	.....	10	..	..	.....
Washington, D. C.	6,767	1.69*[15]	5	.40	9	6	P	1-4-5-5

[11]Miles. [12]7½ and 9 ins. [13]4 and 6 ins. [14]Laid on old granite blocks. [15]$1.63 to $1.67.

TABLE VII.—AVERAGE PRICE OF BITULITHIC PAVEMENT LAID IN 1907 IN 13 CITIES.

	Sq. Yds.	Av. Price per Sq. Yd. Including Base.	Guarantee, Years.	Price per Cu. Yd. for Grading if Paid Separately.	Total Thickness Pavement, Inches.	Concrete Base Thickness, Inches.	Concrete Base Portland or Natural Cement.	Concrete Base Proportions.
Ann Arbor, Mich.	7,109	$2.03*	10	$0.25	8½	6	P	1-8
Charlotte, N. C.	40,000	2.15	5	.....	6	..	..	.....
Fort Worth, Tex.	5,000	2.35	10	.45	6½	..	..	.....
Knoxville, Tenn.	17,450	2.27	8	.....	8	6	N	1-2-4
New Bedford, Mass.	12,802	2.40	5	.....	6	..	..	.....
Niagara Falls, N. Y.	21,241	2.40	10	.....	6	4	P	1-5-8
Portland, Me.	12,507	3.19	5	.....	8	6	P	1-3-8
Providence, R. I.	21,189	2.25	5	.....	6	..	..	.....
Pueblo, Colo.	9,040	2.58	5	.....	8½	..[2]	..[2]	.....[2]
St. Louis, Mo.	101,767	2.15*	5	.....	8	6	P	1-4-7
Syracuse, N. Y.	3,767	2.43*	10	.45	6[3]	..	..	.....
Toledo, O.	11,936	2.38*	5	.....	3[4]	..	..	.....
Troy, N. Y.	5,353	3.25	5	.....	9	6	P	1-3½-7

*Does not include grading.
[1]By city forces. [2]On 6-in. macadam base. [3]2 ins. of bitulithic on 6 ins. of broken stone rolled to 4 ins.
[4]2 ins. of bitulithic on 6 ins. of broken stone.

TABLE VIII.—AVERAGE PRICE OF STONE BLOCK PAVEMENT LAID IN 1907 IN 22 CITIES.

	Sq. Yds.	Av. Price per Sq. Yd. Including Base.	Guarantee, Years.	Price per Cu. Yd. for Grading if Paid Separately.	Total Thickness Pavement, Inches.	Concrete Base — Thickness, Inches.	Concrete Base — Portland or Natural Cement.	Concrete Base — Proportions.
Albany, N. Y.	874	$2.77	2	.....	22½[1]	1	1	1
Buffalo, N. Y.	8,347	3.63	10	.....	15	6	P	1-10
Butte, Mont.	4,520	6.56	..	.....	13[2]	4[3]	P	1-3-6
Cheyenne, Wyo.	550	3.83	..	.....	11	5	P	1-2-5
Cleveland, O.	18,366	3.15*	5	.40	6	..	..	.....
Columbus, O.	13,500	3.25*	5	.50	14	6	P	1-4-8
Elizabeth, N. J.	46,458	2.05	1	.....	12[4]	..	..	.....
Haverhill, Mass.	1,612	1.80[5]	...	.35	16	..	..	.....
Jersey City, N. J.	24,483[6]	1.60	..	.40	6	..	..	.....
Lawrence, Mass.	13,076[7]	....	..	.....	12[8]	4[9]	P	1-3-5
Milwaukee, Wis.	7,484[10]	3.10	..	.....	..	..	..	.....
Minneapolis, Minn.	30,254	2.80[11]	..	.....	8[12]	5	P	1-3-6
New Bedford, Mass.	1,087	3.00	..	.....	16	5	P	1-3-5
Niagara Falls, N. Y.	2,654	3.37	10	.....	12	4	P	1-4
Pittsburg, Pa.	125,307[13]	2.17*	1	.53	15	..[14]	..[14]	....[14]
Portland, Me.	8,445	2.04	..	.....	..	..	..	.....
Providence, R. I.	10,199[15]	....	..	.....	15[16]	6[16]	P	1-3-6
Seattle, Wash.	34,147	3.90*	..	.70	10½	..	..	.....
Superior, Wis.	15,441	2.93*	5	.75	11	5	P	1-2½-5
St. Louis, Mo.	58,330[17]	2.70*	7	.....	12	6	P	1-4-7
Syracuse, N. Y.	718	3.55	10	.....	14[18]	6	P	1-4-7
Tacoma, Wash.	2,565[19]	4.00*	..	.....	11½[20]	4½[21]	P	1-3-6

*Does not include grading.

[1]Granite on a sand base 14 ins. thick. [2]13 to 15 ins. [3]4 ins. to 6 ins. [4]Stone and sand. [5]Sand base. [6]In addition there was 21,694 sq. yds. of stone block repaving done at an average price of $1.50 per sq. yd. [7]Work done by street department. [8]12 to 13 ins. [9]4 to 5 ins. [10]Granite paving; in addition there were 9,625 sq. yds. of limestone block repaving done at an average price of $0.50 per sq. yd. [11]Some of the pavement laid on sand and some on concrete, price ranging from $2.10 to $2.80 per sq. yd. [12]8 ins. to 13 ins. [13]"Ligonier" block. [14]Class "D" gravel base, 9 ins. thick. [15]2,727 sq. yds. with base, 7,472 sq. yds. without base. [16]For pavement with base. [17]Granite. [18]Including 2-in. sand cushion. [19]Miles. [20]11½ ins. and 13½ ins. [21]4½ ins. and 6 ins.

TABLE IX.—AVERAGE PRICE OF WOOD BLOCK PAVEMENT LAID IN 1907 IN 12 CITIES.

						Concrete Base		
	Sq. Yds.	Av. Price per Sq. Yd. Including Base.	Guarantee, Years.	Price per Cu. Yd. for Grading if Paid Separately.	Total Thickness Pavement, Inches.	Thickness, Inches.	Portland or Natural Cement.	Proportions.
Bayonne, N. J.	2,300	....	10	.40	8½	5	P	1-3-6
Bridgeport, Conn.	13,696[1]	$3.035	5	.....	10[2]	6	P	1-4-6
Detroit, Mich.	178,835[3]	2.19	..	.....	..	..	..	.....
Grand Rapids, Mich.	4,990[4]	2.50*	5	.....	10	6	N	1-2-4
Great Falls, Mont.	15,900[4]	4.09*	7	.....	10[5]	5½	P	1-4-7
Holyoke, Mass.	1,383	3.31	..	.....	8	4½	P	1-3-6
La Crosse, Wis.	9,221	2.607	..	.....	10	6	N	1-1½-4
Milwaukee, Wis.	7,749[4]	3.25	..	.....	..	..	..	.....
Minneapolis, Minn.	102,000	2.80	..	.....	10	5	P	1-3-6
Niagara Falls, N. Y.	1,320	2.50[6]	10	.....	7½	4	P	1-4[7]
Oshkosh, Wis.	3,330[4]	3.04	5	.....	11	6	P	1-3-7
Superior, Wis.	7,516	2.89*	5	.70	3	5	P	1-3-7

*Does not include grading.

[1]Wyckoff blocks. [2]3-in. blocks, 1 -in. sand cushion and 6-in. base. [3]Cedar blocks; also 8,104 sq. yds. of creosoted block at $3.08 per sq. yd. [4]Creosoted. [5]Street was paved in 1895 with 6-in. round cedar blocks on concrete base with 10-in. gutters; in 1907 was repaved with 3½-in. creosoted blocks, and the gutters reduced to 7 ins., this change in construction necessitating a filler course of 5½ ins. on top of original base —1-4-7 concrete was used for sand filler course. [6]Does not include foundation or curbing. [7]1-4 base and 1-2 finish.

TABLE X.—AVERAGE PRICE OF MACADAM LAID IN 1907 IN 37 CITIES.

	Sq. Yds.	Average Price Per Sq. Yd.	Guarantee Years.	Price Per cu. yd. for Grading if Paid Separately.	Total Thickness of Pavement Inches.
Albany, N. Y.	1,661	$1.30	2	....	8
Bayonne, N. J.	5,600	...	..	$0.40	9
Brockton, Mass.	39,123	.60	..	....	5-6
Easton, Pa.	22,104	.435	..	....	6-10
East Orange, N. J...	38,150[1]	1.00*	1	.35	12
Elizabeth, N. J......	4,410[1]	1.25	1	....	15
Evanston, Ill.	56,226	1.05*[11]	5	.25[12]	12
Fond du Lac, Wis...	6,000	.70*	1	.50	12
Holyoke, Mass.	27,124	.53	..	....	..
Jersey City, N. J....	8,046	1.00	5	.40	12
Keokuk, Ia.	10,172	.635*	1	.35	10
La Crosse, Wis......	33,529	1.08	..	....	12
Medford, Mass.	29,000[2]	1.50	..	....	..
Milwaukee, Wis.	87,215	.80	..	....	..
Minneapolis, Minn....	20,592	.90	..	....	8-12
Nashville, Tenn.	9,693	1.65[3]	..	....	15
New Bedford, Mass..	29,793	.53	..	....	12
Newton, Mass.......	65,000[4]	.40	..	....	4
Oshkosh, Wis.	14,026	.65	..	....	10
Portland, Me.	22,275	.82	..	....	6
Providence	33,407	....	..	....	8[5]
Racine, Wis.	7,845	1.24*	..	....	..
Richmond, Ind.	38,000	.50	..	....	7
Rockford, Ill.	65,005[6]	.39	..	....	8
Salt Lake City, Utah	64,000	1.00*[7]	..	.77[8]	9
San Antonio, Tex...	280,000[4]	.50	..	....	8
Savannah, Ga.	6,397[9]	.50	..	....	..
Sedalia, Mo.	12,555	.90	5	....	12
Sheboygan, Wis.	4,568	.99	..	....	12[13]
Somerville, Mass....	5,800[4]	.65	..	....	..
South Bend, Ind.....	1,006	.65*	..	.17	6
Superior, Wis.	50,506	1.25*	..	.80	12
Stockton, Cal.	83,000	.52*	..	.50	7
Toledo, O.	10,977	1.40*[10]	..	....	..
Troy, N. Y.	800	1.90	..	....	..
Washington, D. C...	47,300	.80½[14]	..[15]	....	..
Winona, Minn.	8,902	1.00	..	....	12

*Does not include grading.

[1]Telford macadam. [2]About one-half of this was over a marshy soil and 4 ft. average fill, thus making the average price higher than usual; the ordinary cost for 6-in. macadam including excavation and grading is about $1 per yd. [3]Miles of 30-ft. roadway; of this amount 7.43 miles was done by city at $1.65 per lin. ft. and 2.23 miles by contract at $1.79 per lin. ft. [4]By day labor. [5]Loose. [6]Done by City Engineer's department. [7]$0.65 to $1.00. [8]$0.50 to $0.77. [9]Gravel laid on soil. [10]Per lin. ft. [11]$0.92 to $1.05. [12]$0.10 to $0.25. [13]9 ins. limestone, 3 ins. granite. [14]$0.60 to $0.80. [15]By day labor.

TABLE XI.—PRICES OF BRICK, STONE, WOOD AND ASPHALT BLOCK PAVEMENTS.

Report From.	Nature of Foundation.	Thickness of Foundation, Inches.	Cushion Thickness and Character.	Make of Brick or Kind of Block.	Nature of Filler.	Approx. No. Sq. Yds.	Cost per sq. yd. Excl'ding Curb.
Ala., Birmingham	Concrete	5	2" sand	Graves shale brick	Sand	47,500	$1.90
Ariz., Phœnix	"	4	1" "	Purington	Pitch	10,000	3.22
Conn., Bridgeport	"	6	1½" "	Mack block	Cement	5,567	2.79
" "	"	6	1½" "	U. S. Wood Co. wood blk.	Asphalt	874	3.40
" Hartford	"	5	1-2" "	Granite block	Cement	1,000	4.00
Ga., Macon	"	6	1½" "	Reynold's block	Pitch	106,456	2.08
Ill., Cairo	"	5	2" "	Peebles block	Asphalt	50,000	[1]1.99
" Champaign	"	6	1½" "	Culver block	Sand	2,388	1.48
" "	"	6	2" "	" "	Grout	7,000	1.62
" "	"	6	2" "	" "	Asphalt	2,400	1.73
" "	"	6	1½" "	Wood block	"	400	2.60
" Decatur	"	4	2" "	Black Danville brick	Cement & asphalt	4,700	1.65
" "	"	6	2" "	" " "	"	24,275	1.85
" "	"	6	2" "	Terre Haute brick	Asphalt	2,187	2.00
" "	"	4	2" "	Brazil block	Cement	6,773	1.65
" East St. Louis	"	6	"	Albion	"	10,900	1.40
" "	"	6	"	Banner	Asphalt	10,800	1.55
" "	"	6	"	"	Cement	3,500	1.58
" "	"	6	"	"	"	2,850	1.50
" "	"	6	"	"	"	8,100	1.65
" "	"	6	"	"	"	2,500	1.53
" "	"	6	"	"	"	2,950	1.64
" "	"	6	"	Granite block	Sand	12,000	2.27
" Galesburg	"	4	"	Purington block	Cement	4,224	1.67
" Harvey	"	8	1" "	" "	Sand	24,000	1.95
" Joliet	"	6	6" "	Barr brick	"	6,000	1.65
" "	"	6	"	"	"	700	1.94
" La Salle	"	6	2" "	"	"	8,000	1.60
" Moline	"	5	1½" "	Purington block	Cement sand plastic		1.79 to 1.90

Report From.	Nature of Foundation.	Thickness of Foundation, Inches.	Cushion Thickness and Character.	Make of Brick or Kind of Block.	Nature of Filler.	Approx. No. Sq. Yds.	Cost per sq. yd. Excl'ding Curb.
Ill., Taylorville	Concrete	6	2" sand	Springfield brick	Asphalt	9,250	$1.56
" Winnetka	"	8	"	Purington block	Sand	6,000	1.70
Ind., Ft. Wayne	"	6	"	Metropolitan	Cement	15,132	1.65
" "	Broken stone	6	"	"	Sand	2,717	1.30
" Indianapolis	Concrete	6	"	Indiana block	Cement	128,500	2.00
" "	"	6	1" "	Hard pine	"	10,049	2.40
" Kokomo	Old macadam	8	2" "	Culver block	"	8,000	1.30
" Muncie	Concrete	6	1½" "	Metropolitan	"	25,000	1.84
" "	"	6	"	Wassel	"	21,000	1.62
" "	"	6	"	Logan	"	20,000	1.58
" "	"	6	"	Brazil block	"	67,000	[2]1.56
" "	"	6	"	Metropolitan	"	20,000	1.59
" So. Bend	"	6	1" "	Barr block	"	3,010	[3]1.34
" "	"	6	"	Clinton block	"	400	1.37
" "	"	6	"	Indiana block	Sarco cement	5,039	[4]1.32
" "	"	6	"	Trimble block	Pioneer	3,852	[5]1.40
Ky., Covington	"	6½	1½" "	Athens	Cement	12,530	1.85
" "	"	6½	"	Spillman	"	16,000	1.82
" "	"	6½	"	Portsmouth granite	"	4,000	1.73
" "	"	6½	"	" "	"	2,000	1.65
" "	"	6½	"	Carlyle	"	2,900	1.84
Mass., Lawrence	Gravel	6	2" to 3" sand	Granite	"	20,000	2.15
" New Bedford	Concrete	5	2" sand	"	Sand	17,300	3.15
" Springfield	"	4½	Dry cement mortar	Creo-Resinate	Cement	....	3.27
Ill., Chicago	"	6	2" sand	Creosoted wood	Sand	32,270	3.44
" "	"	6	"	" "	Tar	17,900	3.49
" "	Slag	6	"	Purington and Metropol'n	Tar	28,050	2.05
" "	Slag	10	"	Metropolitan	Tar	1,410	2.25
" "	Crushed limest'ne	8	2" "	Metropolitan	Tar	4,900	2.10
" "	Concrete	6	2" "	Various	Tar&grout	68,500	2.55
" "	"	6	2" "	Granite block	Tar	83,700	3.89

[1]$1.99 to $2.04. [2]$1.56 to $1.61. [3]$1.34 to $1.47. [4]$1.32 to $1.44. [5]$1.40 to $1.43.

TABLE XI (Continued).—PRICES OF BRICK, STONE, WOOD AND ASPHALT BLOCK PAVEMENTS.

Report From.	Nature of Foundation.	Thickness of Foundation, Inches.	Cushion Thickness and Character.	Make of Brick or Kind of Block.	Nature of Filler.	Approx. No. Sq. Yds.	Cost per sq. yd. Excl'ding Curb.
Minn., Duluth	Concrete	6	2"			600	2.40
			1½" sand	Sandstone block	Sand	400	-2.70
Mich., Grand Rapids	"	6	1½" "	Metropolitan brick	Cement	15,930	1.80
					asphalt	1,540	1.90
" "	"	6	"	Trimble	Cement	22,300	1.80
" "	"	6	"	Medina block (stone)	"	9,930	3.85
" Kalamazoo	"	6	"	Metropolitan	Asphalt	12,000	1.94
Mont., Butte	"	4	2" "	Granite block	Sand	1,680	3.98
Neb., So. Omaha	"	5	1½" "	Purington block	Sand	34,415	[1]1.97
N. Y., Binghamton	"	6	1½" "	Corning shale brick	Cement	8,975	1.61
" Buffalo	"	6	1" sand or screen'gs	Various	"	16,854	2.60
" "	Macadam	12	"	"	"	2,904	3.06
" Troy	Old granite blocks relaid	8	1" sand	Johnsonburgh	"	5,277	2.30
" "	Concrete	6	1" "	Shawmut	"	396	2.32
" "	"	6	1½" "	Hassom granite block	"	6,350	3.00
" "	"	9	1½" "	" " "	"	6,850	3.00
N. Dak., Grand Forks	"	6	1½" "	Norway and Tamarack creosoted blocks	Tar	37,000	3.02
Ohio, Akron	Sand	10	2" "	Akron brick block	"	25,000	1.07
" "	Slag	8	"	" " "	"	10,000	1.13
" Barberton	Concrete	6	"	Metropolitan	"	22,774	[2]1.73
" Chillicothe	"	6	1" "	Union paver	Cement	4,420	1.39
" Cleveland	Sand	....	....	Collinwood shale blk., 5"	"	3,888	1.41
" "	"	....	....	Bessemer 5" shale block	"	5,101	1.39
" "		8	....	Cleveland 5" shale block	"	3,859	1.79
" "	Concrete	6	2" sand	Cleveland 4" shale block	"	7,771	1.88
" "	"	6	"	Metropolitan 4" shale blk.	"	4,094	2.17
" "	"	6	"	Bessemer 5" shale block	"	7,864	2.54
" "	Sand	8	....	Com. medium sandstone	"	1,091	3.06
" "	Concrete	6	2½" "	" " "	"	1,440	3.08

Report From.	Nature of Foundation.	Thickness of Foundation, Inches.	Cushion Thickness and Character.	Make of Brick or Kind of Block.	Nature of Filler.	Approx. No. Sq. Yds.	Cost per sq. yd. Excl'ding Curb.
Ohio, Cleveland	Sand	8	....	Dressed block medium standstone	Cement	1,529	3.22
" Columbus	Concrete	6	1" sand	Athens, Nelsonville	Tar	....	1.65
" Conneaut	"	5	Yellow sand	Conneaut	Asphalt	20,000	1.63
" Coshocton	Gravel	8	2" sand	Metropolitan	Tar	5,538	1.23
" "	Sand and gravel	0	2" "	Novelty	"	2,720	1.04
" Dayton	Concrete	6	1" "	Portsmouth, Carlyle	Cement	....	1.45
" Findlay	"	6	2" "	Massillon	"	3,676	1.65
" "	Macadam	8	"	Malvern	Tar	2,317	1.41
" Ottawa	"	7	"	Bolen block	Sand	60,000	1.25
" Newark	Gravel	8	"	" "	"	5,015	1.12
" "	"	8	"	Townsend	"	4,995	.99
" "	"	8	"	Logan	"	7,938	1.07
" Springfield	Concrete	6	"	Brick	Pioneer	6,000	1.80
					Cement	2,000	1.60
" "	"	6	¾" sand and cement	Asphalt block	Sand	6,400	1.91
" Toledo	"	6	1½" sand	Various brick	"	95,000	[3]1.30
" "	"	6	1½" cement mortar	Asphalt block	"	12,000	1.30
" Troy	"	6	1½" sand	Townsend	Cement	38,000	1.80
" Youngstown	"	4	"	Bessemer block	Asphalt		1.28
					cement	64,875	-1.43
" "	"	6	"	" "	"	1,235	2.15
" "	"	5	"	" "	"	4,630	2.13
" "	"	4	"	Asphalt block	"	4,360	1.98
Pa., Chester	"	2	2" "	Vitrified shale, brick	"	4,950	2.23
" Scranton	"	6	"	" " "	Cement	3,778	2.17
" Wilkesbarre	"	6	"	Clarified Mfg. Co's brick	"	12,000	1.97
Wis., La Crosse	"	6	"	Purington	Asphalt	3,000	1.90
D. C., Washington	Gravel	5	"	Asphalt block	Sand	26,000	1.65
W. Va., Chester	"	8	"	Fire clay brick	"	43,300	[4].98

[1]$1.97 to $2.18. [2]$1.73 to $1.76. [3]$1.30 to $1.60. [4]$0.98 to $1.14.

TABLE XII.—PRICES OF ASPHALT PAVEMENTS.

Report From.	Kind of Foundation	Thickness of Foundation. Inches.	Binder Thickness and Character	Kind of Asphalt.	Thickness of Asphalt. Inches.	Approximate Number Sq. Yds.	Cost per Sq. Yd. Exclusive of Curb.
Ala., Birmingham	Slag	6	Bitumen	Bithulitic	2	62,000	$1.90
Ariz., Phœnix	Concrete	4	1″	Trinidad	1½	15,000	2.05
Conn., Hartford	"	6	1½″	Bermudez	1½	7,350	City 2.43
						17,242	R. R. 1.90
" "	"	6	1½″	"	1½	1,650	2.78
" "	"	6	2½″	"	1½	3,290	2.35
" "	"	6	1½″	"	1½	316	2.75
Ill., Champaign	"	6	¾″ size stone, 1½″ thick	Obispo	2	9,500	2.15
" Joliet	"	6	2″	Sarco	1½	7,500	2.10
Ind., Auburn	"	5	Stone 1″ size down, 1″thick, gravelscgs	Trinidad	1½	50,000	1.95
" Ft. Wayne	"	6	1″ stone, 1″ thick	Sarco	1½	21,122	1.75
" Indianapolis	"	6	1″	Trinidad	2	107,634	2.00
" Kokomo	"	6	1½″	"	2	11,000	1.80
" South Bend	"	5	1″	"	1	27,788	1.55
Minn., Duluth	"	6	1½″ gravel	"	2	400	2.80
N. J., Camden	"	4	Stone 1″	"	1½	....	1.64
" "	"	6	Stone 1″	Bermudez	2	....	1.99
" Elizabeth	"	6	1½″	Trinidad	2	3,106	2.63
" "	"	6	1½″	"	2	7,000	2.49
N. Y., Buffalo	"	6	1½″	"	2	20,431	in.c'b2.80
" "	Old cement or stone pavm't	6	1½″	"	2	32,326	inc. curb. 2.12

Report From.	Kind of Foundation	Thickness of Foundation, Inches.	Binder Thickness and Character	Kind of Asphalt.	Thickness of Asphalt, Inches.	Approximate Number Sq. Yds.	Cost per Sq. Yd. Exclusive of Curb.
N. Y., Troy	Asphaltic concrete	6	1½" concrete	Trinadad	2	865	2.76
Ohio, Columbus	"	6	1"	"	2	....	2.10
" Dayton	"	6	1" limestone with asphalt cem't	Trinidad	3	....	1.98
" Toledo	"	6	½" stone, 1" thick	Trinidad, Acme Obispo	2	60,000	old b 1.30 new b 1.90
" Youngstown	"	4	1 stone with asphalt cement	Trinidad	2	6,040	repave 1.49
" "	"	6	"	"	2½	10,468	2.33
Pa., Chester	"	6	1½" "	"	2	7,050	2.23
" Erie	"	5	1" broken stone	Bermudez	2	251,236	1.37–1.69
" "	"	5	"	"	2	30,749	1.55–1.75
" "	"	5	"	California	2	5,945	1.65
" Harrisburg	"	6	1"	Bermudez	2	125,000	1.80
" Scranton	"	6	1" gravel with asphalt cement	Trinidad	2	50,161	2.18–2.60
" Wilkesbarre	"	6	1"	"	2	6,000	1.19–1.60
R. I., Providence	"	6	1½" stone	Bermudez	1½	2,408	2.25
D. C., Washington	"	6	2" compressed to 1½"	Bermudez, Cuban California	1½	100,000	1.68
Ill., Chicago	Concrete	6	1½" asphalt cement and limestone	Various	?	581,000	2.03

TABLE XIII.—PRICES OF MACADAM PAVEMENTS.

Report From.	1st Course.			2nd Course.			Material for Binder Course.	Required Thickness Completed, Inches.	Cost Complete Per Sq. Yd. Excluding Curb.
	Thick-ness, Loose, In.	Size of Materi'l In.	Kind of Material	Thick-ness Loose, In.	Size of Materi'l In.	Kind of Material.			
Ala., Birmingham	4	½-2½	Slag	4	dust up	Chert	None	6-8	$.40-.50
Conn., Bridgeport	*4	¾-2	Trap rock	*2	1-1½	Trap rock	Screenings	6	.65
" Hartford	12	6-12	Trap rock	6-8	2	Trap rock	½" and dust	12	.51
Ill., Harvey	6	2½-4	Limestone	6	1½-2½	Limestone	Screenings	12	.98
" Rockford	6	4-6	"	5	1-2½	"	"	8	.40
Ind., Muncie	6	1-4	"	6	½-1	"	"	10	.55
" Richmond	6	2½-4	"	*4	2½	"	"	12	.80
Mass., Lowell	5	2½	Trap rock Slate "	3	1½	Trap rock Slate "	Trap rock Slate "	6	.80
" New Bedford	12	1½-3	Granite	......	......	......	Screenings	12	.50
" Newton	5	2½	Trap rock	2	1½	Trap rock	Dust & scrgs.	6	.70
" Springfield	4-7	2	"	1½	1½	"	"	......	.50-.75
Minn., Duluth	6-8	1	"	1½	1	"	"	7	.70
N. J., Camden	5	2½	"	5	1-11	"	"	8	.95-.98
" "	7	1½-2	"	3	½-1½	"	"	7	1.01
Ohio, Cleveland	9	1-2½	Limestone	3½	1-2	Trap rock	"	12½	2.25
" Columbus	8	½-3	"	6	½-2	Limestone	Screenings	12	.80-.90
" "	5	½-3	"	4-6	½-3	"	"	6-8	.56
" "	8	0-6	Sandstone	6	½-2½	"	"	6-8	.80

Report From.	1st Course. Thick-ness, Loose. In.	1st Course. Size of Materi'l In.	1st Course. Kind of Material	2nd Course. Thick-ness Loose. In.	2nd Course. Size of Materi'l In.	2nd Course. Kind of Material.	Material for Binder Course.	Required Thickness Completed, Inches.	Cost Complete Per Sq. Yd. Excluding Curb.
Ohio, Dayton	6	1-4	Limestone	3	2	"	"	....	1.09
" Springfield	5½	3½-2½	"	5½	1½-2½	"	"	10	.45
" "	4	3½-2½	"	3	1½-2½	"	"	6	.34
" Toledo	5-8	2½-4	"	4-6	1-2½	"	"	7-12	.56
Wis., Lacrosse	8	1-3	"	3	2-5	"	4½" granite with scrg's	12	.90
" Madison	2x4-12x16	6-8	"	4	1-3	"	Screenings	12	.70-.85
" "	6	....	"	6	....	"	"	9	.55-.65
" Sturgeon Bay	7	3-4½	"	5	1½-2	"	"	9	.58½
D. C., Washington	6	2	Trap rock	3	¾ dn.	Trap rock	Scr:enings	6	.60-.75
Ill., Chicago	11	6	Slag	*3	1-2½	Li-restone	Cinders and screenings	....	1.20
" "	*8	6	Slag	*4	1-2½	"	"	....	.79
" "	*6	4	Limestone	*3	1-2½	"	"	....	1.28

* Rolled.

Prices for Estimating Street Work.*—Mr. George P. Carver gives the following prices. They are the prices per square yard on practically all classes of paving, and are used by the engineering department of one of the largest Massachusetts cities for estimating purposes to determine amount necessary for appropriation.

These figures are used, and to the total 10 or 15 per cent is added for incidentals.

The prices in this list are made up from the figures submitted in bids for paving work in that city and are very close to actual figures.

The flagging is granite and North River stone.

The prices given are per square yard unless otherwise stated.

*†Block (granite) paving	$2.35
*††Block (granite) paving	3.20
**††Block (granite) paving	4.10
Telford macadam, 8 ins. plus 4 ins.	1.50
Macadam, 6 ins.	1.00
**Asphalt, 5-yr. guarantee	3.50
**Asphalt, 10-yr. guarantee	3.75
*Paving with old granite blocks	1.00
**Repaving with old granite blocks	2.75
New blocks furnished on ground	1.35
Brick sidewalks	1.10
Gravel sidewalks	0.40
Crushed stone sidewalks	0.70
New bricks furnished	0.55
Laying bricks flat	0.55
†Relaying old bricks	0.15
Cobble gutters, old cobbles	1.25
Tar concrete furnished and laid	1.25
Gravel roadway, 12 ins. deep	0.55
**Wood paving, furnished and laid	3.50
*Bit. brick paving	3.50
Concrete base, 6 ins.	0.83
New flagging, furnished on ground	3.30
†Laying flagging	1.00
†Flagging cross-walks, furnished and laid	4.30
**††Flagging furnished and laid	6.00
**††Flagging furnished and laid	5.15
New edgestone furnished, per lin. ft.	0.70
Setting edgestone, per lin. ft.	0.25
Edgestone furnished and laid, per lin. ft.	0.95
Circular edgestone, furnished and laid, per lin. ft.	1.55
Granolithic sidewalks, per sq. yd.	1.70
Earth excavation (ordinary digging), per cu. yd.	0.38
Rock excavation, per cu. yd.	1.75
Setting manhole covers, each	3.00
Extra work, actual cost plus 15%.	

* Gravel base; † gravel joints; †† pitch and pebble joints; ** concrete base.

Cost of Unloading and Hauling Bricks.—Unloading bricks from a gondola car to wagons, each man will average 100 to 130 sq. yds. of brick per 10-hr. day.

In 8 to 10 mins. a gang of 5 men and the driver will easily load a wagon with enough brick to lay 10 sq. yds., which is equivalent to

*_Engineering-Contracting_, May 16, 1906.

a load of 2 tons. Such a load can be hauled by a team over an ordinary good, level earth street.

In unloading the bricks at the curb line, the driver and another man in the wagon toss brick to two men who stack them up. They will unload the wagon (14 sq. yds.) in 8 to 10 mins.

Summing up we have the following cost of loading and unloading (not including the lost team time):

	Per sq. yd.
0.08 hr. labor loading wagon, at $0.20	$0.0160
0.05 hr. labor unloading wagon, at $0.20	0.0120
Total	$0.028

Since the lost team time, while loading and unloading, amounts to about 20 mins. per load, or 2 mins. per sq. yd., we have a cost of 1.4 cts. per sq. yd., when team time is worth 40 cts. per hr.

A team travels 2½ miles per hr., or 220 ft. per min. Hence the cost of hauling, when the load is 10 sq. yds. or 2 tons, is 3.2 cts. per sq. yd. per mile of distance between the car and the place of unloading.

We have a fixed cost of 2.8 cts. for labor of loading and unloading, plus 1.4 cts. for lost team time, or a total fixed cost of 4.2 cts. per sq. yd. Hence the following rule for the cost of hauling brick:

To a fixed cost of 4.2 cts. per sq. yd. add 3.2 cts. per sq. yd. per mile when the load is 2 tons.

By using two extra wagons, one empty wagon at the car being loaded, and one full wagon being unloaded at the street, the item of "lost team time" can be almost entirely eliminated, for a team can be unhitched from an empty wagon and hitched to a loaded wagon in 1 min., and by fastening a chain from the rear of the loaded wagon to the tongue of the empty, the empty can be pulled up alongside the car ready for loading. When this is done, the "fixed cost" is reduced to 2.8 cts. per sq. yd. Then if 3 tons are hauled per load, as is common on city streets, the cost of hauling brick becomes:

To a fixed cost of 3 cts. per sq. yd. add 2 cts. per mile of haul.

The use of extra wagons is particularly desirable when a smaller gang than 5 men is engaged in loading, for with a smaller gang the lost team time would be correspondingly greater if there were no extra wagons.

Gravity Conveyor for Handling Brick to Pavers From Stock Piles Without Breakage.*—Fig. 8 shows a simple device for handling paving brick from stock piles at the sides of the street to pavers, which has been successfully used by Carlson & Theselius, brick paving contractors, Chicago, Ill., in paving work in Chicago and other western cities. The usual method of handling brick is by wheelbarrows. The barrows are loaded at the stock piles by wheelers, wheeled onto the street and dumped. There the dumped brick are arranged ready to the hand of the pavers by pilers. For say

**Engineering-Contracting*, April 21, 1909.

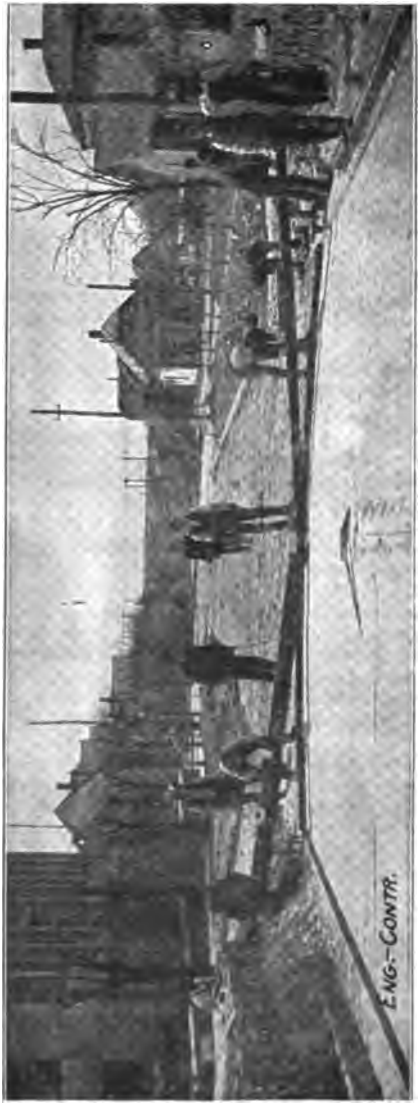


Fig. 8. Gravity Conveyor for Paving Brick.

three pavers laying 1,500 sq. yds. per day there will be required eight wheelers and four pilers to handle the brick. In addition the loading and dumping of the brick results in more or less breakage. With the device illustrated it has been found easily possible to supply bricks to three pavers laying 1,500 sq. yds. per day with only four men, a saving of eight men over wheelbarrow work.

The general arrangement of the device on the work is shown by Fig. 8. The device is merely a set of conveying rolls. Two boards 5 ins. wide are set parallel and carry between them a train of wood spools. The axles of the spools extend through bushed holes in the side boards and have removable nuts at the ends, which permit oiling. The spools are spaced so as to have a clearance of ⅛ in. They are ordinary wooden spools, with a barrel 3⅝ ins. long between shoulders. They are set so that the line of the shoulders is just below the top edges of the side boards; this permits a steel strap guard to be fastened to the top edge of each side board so as to extend inward over the shoulders and prevent dirt and chips from lodging between the ends of the spools and the adjoining side boards. Below the journals the side boards are thinned down so as to permit such debris to fall out easily. The whole construction is very simple and forms, as has been stated, a train of rolls which, when set at an incline, will allow a brick, when set edgewise on the spools, to move from top to bottom by gravity.

The conveyors described above are usually made in 16-ft. lengths. They may, of course, be made longer, but a 16-ft. length is easily carried by one man, and when much longer conveyors are needed two or more 16-ft. sections can be coupled end to end. When used on the street the ends of the conveyors near the sides of the street are supported on standards extending up from small trucks or carriages which travel along the gutter. This method of support can be seen in the illustration. Two conveyors are employed, one extending into the street from each side. The inner ends of the two conveyors meet at the center of the street and the outer ends extend beyond the supporting trucks and the gutters and past the ends of the stock piles. Just back of the trucks there is a hinge in each conveyor which permits the projecting end to be tilted up to clear trees, poles or other obstructions when the conveyors are shifted ahead. The incline given the conveyor is as flat as may be, so that the brick can be put on and taken off the conveyor with as little lifting as possible. An incline of 1 in. to 1 ft. is ample; in fact it has been much flatter on most of the work done by Messrs. Carlson and Theselius. In one case the incline was only 14 ins. in 24 ft.

The method of operating the conveyors is quite clearly shown by the illustration. The loaders take the bricks from the piles and set them edge up and endwise on the spools. The movement of the brick is then by gravity down the conveyor. In putting the brick on the conveyor the loaders take care to place the best or smooth edge up, so that when the pavers take them off they do not have to turn them to find the best edge to come on top. The pavers

grasp a brick in each hand and place both at once. The loaders take care, in placing the brick on the conveyors to keep the supply just ahead of the laying. If the conveyor is kept tight packed with brick all the time, they bind and the paver has to exert more force in lifting them, which reduces his speed.

As stated above, with three conveyors a gang of seven men, four loaders and three pavers, will lay 1,500 sq. yds. of paving a day. This record has been frequently made by the contractors named above. These contractors have patented the device and are putting it on the market. They will furnish these conveyors made up in 16-ft. lengths or longer at $2 per lineal foot.

Cost of Laying Bricks.—Bricks are ordinarily carried in wheelbarrows from the piles along the curb and dump on the finished pavement behind the bricklayers. The average wheelbarrow load is about 40 "pavers," or 270 lbs., and is seldom more than 45 "pavers," or 305 lbs. Such loads are readily wheeled over level runways and even up a short slope of 1 in 7. A man will readily load a barrow in 1¾ mins., at which rate, if he were doing nothing else but load barrows he would average 14,000 "pavers" loaded in 10 hrs. But the men who load the bricks usually wheel them to place and dump them. Where the distance to be wheeled is about 40 ft., it takes about ⅜ min. to go and return plus another ⅜ min. lost in dumping the barrow and in brief rests; so that a day's work is 10,000 "pavers," or 175 sq. yds., loaded and wheeled 40 ft.

Two men wheeling bricks to each bricklayer is a common ratio, and 300 sq. yds. laid per day by a bricklayer is considered a big day's work, although it is frequently exceeded. This would require the wheeling of 150 sq. yds. per man on wheelbarrow.

Foremen are often very careless in spacing the wagon loads of brick along the curb, so that there are frequently too many bricks at one part of the street, and too few at another. When this is so, more men with wheelbarrows are required to deliver the bricks.

The number of men to each bricklayer is ordinarily about as follows:

		Per day.
1	bricklayer	$ 2.50
2	men wheeling and delivering bricks	3.50
1	man spreading sand cushion	2.25
1	man ramming	1.75
1½	men grouting joints with cement	2.65
½	man raising sunken brick, etc.	0.85
7	men total	$13.50

When the bricklayer, who really "sets the pace," lays 300 sq. yds. per day, the cost of laying and grouting is $\$13.50 \div 300 = 4\frac{1}{2}$ cts. per sq. yd., to which ½ ct. must be added for foreman and water boy, making a total of 5 cts. per sq. yd. for laying the brick. This is a cost that may be attained under good management, and with skilled men. It is, perhaps, nearer an average to say that 225 sq. yds. per day are commonly laid by each bricklayer, making the cost of laying 6 cts. per sq. yd., exclusive of foreman and

water boy, or 6.6 cts. including them, assuming that a foreman supervises about 20 men, and that wages are as above given.

Summary of Cost of Brick Pavement.—Based upon the foregoing data, we may summarize the cost of a brick pavement, bricks laid on edge, grouted with 1 to 1 cement mortar, as follows:

Materials:	
55 "pavers," at $15.00 per M	$0.825
0.042 cu. yd. sand for cushion 1½ ins. thick, at $1.00	0.042
0.004 cu. yd. sand for grouting joints, at $1.00	0.004
0.028 bbl. cement for grouting joints, at $1.50	0.042
Total materials	$0.913
Labor:	
Hauling brick 1 mile (2 + 3 cts.)	$0.050
Laying brick and grouting	0.050
Total labor	$0.100
Total materials and labor	$1.013
1/6 cu. yd. concrete base, at $3.60	0.600
⅓ cu. yd. earth excavation, at $0.30	0.100
Grand total	$1.713

The above costs of concrete base and of earth excavation are merely assumed for illustration, the details of those classes of work being given elsewhere.

The cost of filling of the joints of a brick pavement is discussed in detail in the next paragraph.

Cost of Filling Joints of Brick Pavement.—To determine the area of brick pavement occupied by the joints, refer to the table on page 359. It will be noted there, for illustration, that 2½ x 8½ x 4-in. bricks laid on edge require 57.2 bricks per sq. yd. when laid with ⅛-in. joints, or 61 bricks if it were possible to lay them so close that there would be no joints. Hence the joints occupy an area equivalent to $61.0 - 57.2 = 3.8$ bricks per sq. yd. But $3.8 \div 61 = 6.2\%$, which is the percentage of area occupied by joints. Since the joints are 4 ins. deep, each sq. yd. of pavement contains $6.2\% \times (4 \div 36) = 0.007$ cu. yd. of grout or tar used to fill the joints. If cement grout is used, then the amount of sand and cement per cu. yd. for any specified proportions is ascertained by referring to Tables I and II in the Concrete Section.

Thus, Table I shows that about 4 bbls. of cement and 0.6 cu. yd. of sand are required per cu. yd. of 1 to 1 mortar. Hence a sq. yd. of brick pavement laid with pavers will require 0.007×4 bbls. = 0.028 bbl. cement, and 0.007×0.6 cu. yd. = 0.0042 cu. yd. sand.

In like manner, we find that about 2¾ bbls. cement and 0.8 cu. yd. of sand are required per cu. yd. of 1 to 2 mortar. Hence, $0.007 \times 2¾ = 0.019$ bbl. cement will be required to grout a sq. yd. of brick; and $0.007 \times 0.8 = 0.0056$ cu. yds of sand.

If paving blocks, 3¼ x 8½ x 4 ins., are laid with ⅛-in. joints, it will be seen on page 359 that 44.5 blocks lay a sq. yd., while without joints it would require 46.9 blocks, or a difference of 2.4 blocks, which is 5.1% of the area. Hence, using the same method of

analysis as above given, it would require 5.1% × (4 ÷ 36) = 0.0057 cu. yd. of grout or tar to fill the joints. Therefore it would require 0.023 bbl. cement and 0.0034 cu. yd. sand to fill the joints of a square yard of blocks with a 1 to 1 grout. With a 1 to 2 grout, it would require 0.016 bbl. cement and 0.0046 cu. yd. sand per sq. yd.

If a tar or pitch filler is used, the 2½ x 8½ x 4-in. "pavers" will require 0.007 cu. yd., or 0.19 cu. ft. of tar per sq. yd. Since there are 7½ gals. per cu. ft., this is equivalent to 1.3 gals. per sq. yd. Tar is usually sold in 52-gal. barrels, but the size of the barrel should always be specified.

If 3¼ x 8½ x 4-in. "blocks" are used, 0.0057 cu. yd., or 0.15 cu. ft., or 1.1 gal. of tar will be required per sq. yd.

Tar has a specific gravity of 1.25, and therefore weighs 78 lbs. per cu. ft., or a trifle more than 10 lbs. per gal.

As above given, the labor of grouting joints of "pavers," including mixing the Portland cement and sand and brooming it into the joints, is less than 1 ct. per sq. yd., where the men work at all vigorously, but even this is equivalent to $0.01 ÷ 0.007 cu. yd. = $1.40 per cu. yd. of cement grout, and is, therefore, susceptible of considerable reduction, as will be seen by subsequent examples.

The labor cost of melting and pouring tar into joints is usually about 1 ct. per gal., when wages are $1.75 per 10 hrs.

Number and Weight of Paving Brick Per Square Yard.—The so-called "standard brick" for house building is 2¼ x 8¼ x 4 ins., and for a time brick for paving purposes were also made of the same dimensions. Within recent years the size of the standard brick for paving purposes has become 2½ x 8½ x 4 ins., and such bricks are commonly called "pavers." It takes 52 to 57 of these "pavers" per sq. yd. A lårger size, 3¼ x 8½ x 4 ins., is also much used, and is known as "block.' Some variations from these dimensions occur, as in Hallwood block, which is 3 x 9 x 4 ins.; and as neither the engineer nor the contractor can be sure of the exact side of brick that will be delivered, it is always necessary to secure from manufacturers a statement as to the sizes they make.

When the sizes are known there is a factor of uncertainty to the inexperienced, and that is the thickness of the grouted or tarred joints between bricks as ordinarily laid. I have found as the average of a large number of measurements that the thickness of the average joint is about ⅛ in., unless the "pavers" are made with projecting lugs to give a wider joint.

The following table gives such data as will ordinarily serve in estimating the number of brick that will be required. Brick are occasionally laid with extremely close joints about one-sixteenth inch, in which case about 3% more "pavers" laid on edge will be required than given in the table, but close laying is not only expensive work for the contractor, but objectionable also in that it is then impossible to fill the joints perfectly.

For street pavements the bricks or blocks are laid on edge (mak-

ing a brick pavement 4 ins. thick), but for sidewalks they are usually laid flatwise. *I believe that in residence streets the bricks should usually be laid flatwise for true economy's sake.*

Size of Brick.	No. of Brick Per Square Yard. With ⅛-in. Joints.	No Allowance for Joints.
2¼ x 8 x 4, laid flatwise	38.7	40.5
2¼ x 8 x 4, laid edgewise	67.1	72.0
2¼ x 8¼ x 4, laid flatwise	37.5	39.3
2¼ x 8¼ x 4, laid edgewise	65.1	69.8
2½ x 8½ x 4, laid flatwise	36.4	39.3
2½ x 8½ x 4, laid edgewise	57.2	61.0
3¼ x 8½ x 4, laid flatwise	36.4	38.1
3¼ x 8½ x 4, laid edgewise	44.5	46.9
3 x 9 x 4, laid flatwise.............	34.4	36.0
3 x 9 x 4, laid edgewise	45.5	48.0

Having obtained the price per thousand (M) for the paving brick, f. o. b. factory, and freight rate to destination, the weight of the bricks must be known to estimate total cost f. o. b. cars at destination. The specific gravity of paving brick ranges from 1.9 to 2.7. Tests of 12 Ohio makes show a range of 1.95 to 2.25.

Assuming a specific gravity of 2.2, a square yard of brick pavers 4 ins. thick would weigh 385 lbs., and a square foot would weigh 43 lbs., as laid with ⅛-in. joints. Whence, by taking from the bidding sheet the number of quare yards of pavement and multiplying by 385, the total weight is readily ascertained; or, *for all practical purposes, divide the number of square yards by 5, and the quotient will be the number of short tons of freight.*

It is convenient to remember that a "paver" (2½ x 8½ x 4 ins.) weighs about 6¾ lbs. and a "block" (3¼ x 8½ x 4 ins.) weighs 8¾ lbs. These are actual averages of several makes of New York State bricks that I have used.

Cost of a Brick Pavement, Champaign, Ill.—Mr. Charles Apple gives the following data on the cost of a brick pavement laid in 1903 at Champaign, Ill. The work was done by contract, the contract price for grading being 23 cts. per cu. yd., and for brick pavement on concrete base, $1.29 per sq. yd.

The grading was done with drag-scoop scrapers, wheel-scrapers and wagons, each being used as demanded by the length of haul. Earth was loosened with plows to within 3 ins. of subgrade and this last layer then removed with pick and shovel.

The cost of removing the last 3 ins. was 2 cts. per sq. yd. (or 24 cts. per cu. yd.) with labor at $1.75 per day of 10 hrs. There was a total of 26,715 cu. yds. of grading, and there were 38,504 sq. yds. of pavement.

The subgrade was compacted with a horse-roller weighing 150 lbs. per lin. in. at an average cost of about 0.05 cts. per sq. yd.

The concrete foundation was 6 ins. thick, composed of 1 part natural cement, 3 parts of sand and gravel, and 3 parts of broken stone. All the materials were mixed with shovels, and were thrown into place from the board upon which the mixing was done. The material was brought to the steel mixing board in wheel-

barrows from piles wnere it had been placed in the middle of the street, the length of haul being usually from 30 to 60 ft.

When the concrete base had set, a sand cushion 1¼ ins. thick was placed upon it, and upon this the brick wearing surface was laid.

The cost of the brick wearing surface is given in the following table, and is based upon the assumption that 1,000 paving blocks will lay 25 sq. yds. of pavement, or 40 blocks per sq. yd. This ratio was determined by actual count after the pavement was laid. To this cost will have to be added something for rejected bricks, the amount depending upon how closely the inspection is done at the kilns.

COST OF 6-IN. CONCRETE BASE FOR PAVEMENT.

	No. of men.	Sq. yds. per day.	Total wages.	Cost per sq. yd.
Rolling subgrade (1 roller, 2 teams, 1 driver)	1	8,000	$ 4.75	$0.0005
Mixing and tamping concrete:				
Turning with shovels	6	.....	12.00	....
Throwing into place	4	.....	8.00	....
Handling cement	2	.....	3.50	....
Wetting with hose	1	.....	1.75	....
Tamping	2	.....	3.50	....
Grading concrete	1	.....	1.75	....
Wheeling stone	6	.....	10.50	....
Wheeling gravel	4	.....	7.00	....
Foreman	1	.....	4.00	....
Total	27	900	$52.00	$0.0580
Total labor per sq. yd.				$0.0585
Materials:				
0.2 bbl. cement, at $0.50			$0.10	
0.1 cu. yd. sand and gravel, at $1.00			0.10	
0.1 cu. yd. broken stone, at $1.40			0.14	$0.3400
Total for material and labor per sq. yd.				$0.3985

This is practically 40 cts. per sq. yd., or $2.40 per cu. yd. of concrete for materials and labor. It will be noted that the labor cost of making and placing the concrete was only 35 cts. per cu. yd., average wages being nearly $1.85 a day. Excluding the foreman, the 26 men placed 900 sq. yds. or 150 cu. yds. per day, which is nearly 6 cu. yds. per man. This record is so abnormally high that I am satisfied the concrete did not measure 6 ins. thick, as stated by Mr. Apple. Certainly 0.2 cu. yd. of stone and sand combined could not make a sq. yd. of 6-in. concrete. It is more than likely that the compacted concrete actually did not measure much more than 4 ins. thick.

The cost of hauling and laying the brick blocks (40 per sq. yd.) was as follows:

Hauling Brick:	Per sq. yd.
0.01 day labor loading wagons from car, at $1.75	$0 0175
0.08 day team hauling, 1 mile at $3.00	0.0240
0.008 day labor unloading at curb line at $1.75	0.0140
Total, hauling brick	$0.0555

Laying Brick:

0.0033 day labor, spreading sand cushion, at $1.75	$0.0057
0.0066 day wheeling brick to layers, at $1.75	0.0115
0.0033 day bricklayer, at $2.50	0.0083
0.0022 day labor, sweeping and filling joints with sand, at $1.75	0.0039
0.0012 day team rolling pavement, at $3.00	0.0037
Total, laying brick	$0.0331
Grand total, labor, hauling and laying	$0.0886

Materials:

0.0277 cu. yd. sand cushion (1 in.), at $1.00	$0.0277
40 brick block f. o. b. destination, at $16.00 per M	0.6400
0.0023 cu. yd. sand filler, at $1.00	0.0023
Total materials	$0.6700

The following is a summary of the foregoing:

	Per sq. yd.
0.435 cu. yd. grading, at $0.23	$0.1000
0.167 cu. yd. concrete base	0.3985
Brick and sand cushion	0.6700
Hauling brick	0.0555
Laying brick	0.0331
Grand total	$1.2571

The contract price was $1.29. Note that the joints were filled with sand and not with grout.

It will be seen that each man loading blocks from car to wagon averaged 100 sq. yds., or 4,000 blocks, per 10-hr. day; and that each man unloading wagons averaged 125 sq. yds., or 5,000 blocks per day. Each bricklayer averaged 300 sq. yds. and each man wheeling bricks to the layer averaged 150 sq. yds.

Cost of 80,000 Square Yards of Brick Pavement, Iowa.—The following is quoted from *Engineering-Contracting*, June 23, 1909. During 1905 and 1906, a large amount of brick paving and cement curb was built at Centerville, Ia., by contract. Mr. M. G. Hall required the inspectors to keep a careful force account of the work done, and the following data are a summary of the records thus gathered.

Purington paving bricks were laid on a concrete base, with a 1½-in. sand cushion between. The joints were filled with a 1:1 cement grout. Expansion joints of asphalt filler were provided from curb to curb, every 50 ft., and along each curb. The following costs do not include grading.

The concrete base was a 1 : 3½ : 6 mixture and it was machine mixed. There appears to have been a serious error made either in recording or in calculating the amounts of cement, sand and broken stone used, for, as will be seen below, Mr. Hall's data show about two-thirds as much of each of these materials per cubic yard as are required by a 1 : 3½ : 6 mixture. Mr. Hall's data were originally published in "Engineering News" April 2, 1908, and were not there analyzed as we have analyzed them below, which probably accounts for his failure to discover the discrepancy. This emphasizes the importance of using the cubic yard as

the unit in checking up costs of concrete, instead of relying solely upon the square yard.

Our analysis of the cost of the 5-in. concrete base, for three jobs aggregating 58,000 sq. yds., shows the following:

	Cts. per sq. yd.
Sand wheelers, at 20 cts. per hr.	12.24
Concrete wagons, at 40 cts. per hr.	8.42
Men on mixer, at 22¾ cts. per hr.	5.62
Spreaders, at 22½ cts. per hr.	5.47
Tampers, at 20 cts. per hr.	1.93
Water boy, at 10 cts. per hr.	0.72
Extra men, at 20 cts. per hr.	1.93
Foreman, at 30 cts. per hr.	1.93
Coal for mixer, at $2.50 per ton	1.58
Total labor	39.84

This is practically 40 cts. per cu. yd., exclusive of interest, depreciation and repairs on mixer. Since the concrete was 5 ins. thick, divide any of the above items by 7.2 to get the cost per square yard.

According to Mr. Hall's records, the cost of materials was as follows, when reduced to the cubic yard basis:

	Per cu. yd.
0.56 bbl. cement, at $2.00	$1.12
0.40 ton sand, at $0.70	0.28
0.52 cu. yd. stone, at $1.20	0.62
Hauling cement	0.02
Hauling sand	0.14
Hauling stone	0.29
Total materials	$2.47

The sand weighed 2,700 lbs. per cu. yd., and the stone weighed 2,626 lbs. per cu. yd.

Since the materials would have to be about 50 per cent more than above given to make a cubic yard of concrete tamped in place, there is evidently an error, and the cost of materials, at the unit prices given, would be about $3.70 per cu. yd., instead of $2.47.

The cost of laying 58,000 sq. yds. of brick pavement was as follows:

	Cts. per sq. yd.
Brick wheelers, at 20 cts. per hr.	1.52
Bricklayers, at 22½ cts. per hr.	0.88
Men spreading sand, at 22½ cts. per hr.	1.05
Water boy, at 10 cts. per hr.	0.15
Other men, at 20 cts. per hr.	0.96
Foreman, at 30 cts. per hr.	0.41
Total	4.97

By dividing the square yard cost of any item into the corresponding rate of wages, the number of square yards per hour is obtained. Thus, each bricklayer laid 22.5 ÷ 0.88 = 25.6 sq. yds. per hr., or 256 sq. yds. per day. Since there were 53 bricks per sq. yd., this is equivalent to 13,568 bricks per bricklayer, which is an excellent output.

On another job, where 26,300 sq. yds. were laid, the cost of laying was as follows:

	Cts. per sq. yd.
Brick wheelers, at 20 cts.	1.05
Bricklayers, at 25 cts.	0.75
Brick handlers, at 20 cts.	0.26
Men spreading sand, at 25 cts.	0.76
Men wheeling sand, at 20 cts.	0.06
Patchers, at 20 cts.	0.21
Water boy, at 10 cts.	0.28
Other men, at 20 cts.	0.21
Foremen, at 30 cts.	0.32
Total	3.70

Here each bricklayer averaged 330 sq. yds. per 10-hr. day; and, as there were 56 bricks per sq. yd., this is equivalent to 18,480 bricks per bricklayer per day. There was a car track down the center of this street.

The cost of the bricks ranged from 76½ to 80 cts. per sq. yd., the following being a fairly typical cost of the materials and labor:

	Per sq. yd.
53 bricks, at $15 per M.	$0.800
Hauling bricks	0.035
Sand for 1½ in. sand cushion, at 96 cts. per cu. yd. delivered	0.041
Total materials	$0.876
Labor laying brick, as above detailed	0.050
Total	$0.926

The joints were filled with a 1:1 cement grout, the cost of which was as follows for 58,000 sq. yds.:

	Cts. per sq. yd.
Screening sand, at 20 cts. per hr.	0.05
Dry mixers, at 22½ cts. per hr.	0.15
Wet mixers, at 20 cts. per hr.	0.20
Rubbers, at 20 cts. per hr.	0.43
Wheelers, at 20 cts. per hr.	0.13
Other men, at 20 cts. per hr.	0.03
Water boy, at 10 cts. per hr.	0.04
Foreman, at 40 cts. per hr.	0.14
Total labor	1.17
0.017 bbl. cement, at $2.00	3.40
0.034 ton sand, at $1.05	0.35
Grand total	4.92

On the 26,300 sq. yd. job the labor of grouting was only 0.9 cts. per sq. yd.

The cost of the expansion joints (every 50 ft. and along each curb) was as follows per sq. yd. of pavement:

	Cts. per sq. yd.
Labor, at 20 cts. per hr.	0.32
Pitch, at $4.80 per bbl.	0.89
Total	1.21

Summing up we have:

	Per sq. yd.
Concrete, labor	$0.06
Concrete materials (too low)	0.34
Bricklaying, labor	0.05
Brick and sand cushion	0.88
Grout, labor	0.01
Grout, materials	0.04
Expansion joints, labor and materials	0.01
Grand total	$1.39

For costs of cement curb on this job, see page 449.

Cost of Laying Brick Pavement, Gary, Ind.*—Mr. E. M. Scheflon gives the following. In 1908, Madison street was paved by contract for 8,800 ft. long by 38 ft. wide. The brick pavement was laid on a natural sand base, and grouted with cement. Common laborers received $2 per 10 hrs. The labor cost of laying the brick, not including the cost of hauling the brick to the street, was as follows:

	Per sq. yd.
0.00255 day labor, preparing subgrade, at $2.00	$0.0051
0.0194 day labor, carrying bricks, at $2.00	0.0388
0.00318 day bricklayers, at $3.50	0.0112
0.0002 day team, rolling, at $5.50	0.0011
0.0036 day labor, grouting, at $2.00	0.0072
Total labor, 16,800 sq. yds.	$0.0634

It will be noted that there were 6 men carrying brick to each bricklayer, and that each bricklayer laid ($3.50 ÷ $0.0112) 312 sq. yds. per day. This is an excellent output for the bricklayers, but a very poor showing for the men who delivered the brick, apparently due to the fact that they did not use wheelbarrows.

Cost of Laying Bricks, New York State.—On one job, 30,000 "pavers" were laid per day by the gang of 4 bricklayers and 10 men, or 132 sq. yds. per bricklayer. The management was fairly good, but the bricklayers worked with no energy. The other men worked well.

	Per sq. yd.
4 pavers, at 25 cts. per hr., each	1.9
3 laborers wheeling, at 15 cts. per hr.	0.8
1 laborer spreading sand, at 15 cts. per hr.	0.3
3 laborers grouting, at 15 cts. per hr.	0.9
2 laborers ramming, at 15 cts. per hr.	0.5
1 laborer raising sunken brick, at 15 cts. per hr.	0.3
1 foreman, at 30 cts. per hr.	0.6
Total	5.3

Bricks Laid Per Day Per Man, Jackson, Mich.—In paving a street with shale brick, at Jackson, Mich., in 1895, there were about 200,000 bricks used for 3,500 sq. yds., or 57.1 bricks per sq. yd. The bricks were 2¾ x 4⅛ x 8 ins., with rounded corners. On a street 42 ft. wide, 6 bricklayers, supplied with brick by helpers, laid 70,000 bricks in 9 hrs. or 11,666 bricks, or 204 sq. yds., per

*Engineering-Contracting, Oct. 14, 1908.

bricklayer. The ordinary average, however, was 7,000 bricks, or only 123 sq. yds., per bricklayer per day. Note that the average day's output was only about two-thirds the best day's output. It is evident that these bricklayers did not exert themselvs, for even their best day's record of 204 sq. yds. per layer per day lacks 50% of being as large a day's work as is recorded elsewhere in this book.

Twelve boys filled the joints with tar. To do this a cone-shaped pouring can was used. There was a stopper in the point of the cone, controlled by a rod leading to the hand of the workman.

Cost of a Brick Pavement in Minneapolis.—Mr. Irving E. Howe gives the following data on laying 17,000 sq. yds. of brick pavement in 1897. The work was not done by contract, but by day labor. Six weeks were required with a force of about 65 men. An old cedar block pavement on a plank foundation had to be removed, and the street graded. The subgrade was rolled with a 7-ton horse roller. A 6-in. concrete foundation was then laid, in proportion of 1 natural cement, 2 sand, 5 broken stone. There were required 1.16 bbls. of natural cement per cu. yd. of concrete, at 76 cts. per bbl. The stone cost $1.15 cts. per cu. yd. delivered, and the sand cost 30 cts. per cu. yd. delivered. The total cost of the concrete laid was $2.80 per cu. yd. Laborers mixing received $1.75 per day. The Purington Paving Brick Co., of Galesburg, Ill., furnished 198 car loads of brick, 2¼ x 4 x 8-in. size, guaranteed to lay 56 to the sq. yd., costing the city $15.50 per M, or 87 cts. per sq. yd. on the cars at Minneapolis. The manufacturers guaranteed the bricks for ten years. A 1-in. sand cushion was laid on the concrete. To secure a perfect crown 1-in. strips of wood were nailed to the concrete every 12 ft., from curb to curb. An iron shod straight edge or scraper was placed on these strips and dragged across the street to bring the sand cushion to a perfect surface. Then one of the wood strips was pulled up and moved ahead. After a block of bricks had been laid, they were rolled with a roller, broken bricks replaced, and the joints grouted under a special contract of 17½ cts. per sq. yd. for the grouting. Exclusive of this grouting the actual cost per square yard was as follows:

	Per sq. yd.
Removing old cedar paving	$0.035
Grading	0.032
Concrete, natural cement, 6 ins. thick	0.467
Planking over concrete, lumber, etc.	0.008
56 bricks, at $15.55 per M	0.870
Hauling brick	0.038
Sand cushion, 1-in., at 65 cts. cu. yd.	0.018
Laying brick	0.032
Total per sq. yd. (not including grout)	$1.500

The pavers received $2 a day, laborers $1.75, teams $3.50. It will be noticed that the hauling cost 68½ cts. per M of bricks.

Cost of a Brick Pavement, Memphis, Tenn.—Mr. Niles Meri-

wether gives the following data on the cost of 1,300 sq. yds. of brick pavements laid by day labor (probably colored) in 1893:

Concrete base (8-in.):	Per sq. yd.
Natural cement, at $0.74 per bbl.	$0.19½
Sand, at $1.25 per cu. yd.	0.07½
Broken stone, at $1.87 per cu. yd.	0.35½
Labor hauling stone and making concrete	0.15½
Total concrete	$0.68
Sand cushion	0 07
62 paving bricks, at $18.20 per M.	1.13
1-25 bbl. pitch, at $5.25	0.21
Sand used in pitching	0.01
Labor paving and pitching	0.15
Total	$2.35
Grading and removing old material	0.23
Grand total	$2.58

The cost of curbs distributed over the pavement added 10 cts. more per sq. yd. Common laborers were used to lay the bricks, at $1.25 to $1.50 per day of 8 hrs. The mortar for concrete was mixed 1:2, and enough mortar used to fill the voids in the stone. It took 1.36 bbls. of Louisville cement per cubic yard of concrete. On three other jobs of about the same size, the costs were practically the same as above. On one street Hallwood blocks were used, requiring 50 blocks per sq. yd., and 1 bbl. of pitch for every 25 sq. yds. On one job, where Virginia paving bricks were used 56 bricks were required per sq. yd., and the labor cost of laying the brick and pitching the joints was 11 cts. per sq. yd.

It will be noted that the cost of materials was unusually high, and that the labor was not efficient.

Cost of Brick Pavement, Baltimore, Md.—In *Engineering-Contracting*, Aug. 18, 1909, was published an article giving the costs of various kinds of pavements laid in 1908 by forces in the employ of the city of Baltimore. I give the following excerpts merely to show the enormously high costs that invariably occur when such work is done by city day labor instead of by contract.

In laying one brick pavement, the labor of mixing and placing the 6-in. concrete base was $0.217 per sq. yd., or $1.30 per cu. yd. of concrete. It never costs a capable contractor more than half this, even when he does not use a concrete mixer, and I have known many contractors to mix and lay concrete for 5 cts. per sq. yd., 6 ins. thick, or 30 cts. per cu. yd., when a machine mixer was used, as recorded subsequently in this book.

In laying the bricks for this same street, the labor cost $0.342 per sq. yd. This does not include $0.096 per sq. yd. for hauling the brick. Brick blocks were used, averaging about 40 per sq. yd., and costing $25 per M, or $1.00 per sq. yd.

On another street (8,400 sq. yds.) the "vitrified brick paving, labor and materials" cost $1.56 per sq. yd. Since brick cost $1 per sq. yd. and paving sand cost $0.65 per cu. yd., it is evident that the labor item of laying the brick was even greater than on the other street above given. The $1.56 does not include the 6-in. con-

crete base, which cost $0.676 per sq. yd., nor the excavation, which cost $0.099 per sq. yd.

Almost as bad an example of the inefficiency of the day labor system is given in the next paragraph.

Cost of Removing, Chipping Off Tar and Relaying Brick.—It is frequently desirable to know what the cost will be of taking up, cleaning old brick and relaying. A gang of men, working leisurely, "by the day for the city," accomplished the following in Rochester, N. Y. Each laborer chipped the tar off 500 to 700 bricks in eight hours. Replacing a strip of pavement 4 ft. wide over a sewer required a gang of 17 men, employed as follows, after the pavement had been removed and concrete relaid:

	Wages for 8 hrs.	Cost per sq. yd.
3 men toothing or chipping out bats	$ 4.50	$0.08
6 pavers	15.00	.25
2 men furnishing brick	3.00	.05
2 men ramming, etc.	3.00	.05
4 men melting and pouring tar	6.00	.10
Total	$31.50	$0.53

The average per 8-hr. day by the above gang was 60 sq. yds., the best day's work being 70 sq. yds.

It seems almost incredible that the cost of such repaving was 53 cts. a sq. yd., but it well illustrates the inefficiency of day labor for a city.

Cost of Chipping Tar Off Bricks.—When a brick pavement with tar joints is taken up, the tar must be chipped off the old bricks before re-laying them. This is usually done with a hatchet, after cooling the bricks in a bucket or tub of water. As an average of a good many thousand brick thus cleaned, I found that one laborer, working deliberately, could be counted upon to clean 60 bricks per hour. With wages at 15 cts. per hr., this is equivalent to $2.50 per M for cleaning the bricks.

Cost of Removing and Replacing a Brick Pavement.—Mr. C. D. Barstow gives the following relative to removing a strip of brick pavement 3 ft. wide and 373 ft. long, preparatory to digging a trench. The pavement was laid on a concrete base 7½ ins. thick. The laborers were negroes, and the work was done in 1892 in a Southern city. Laborers received $1.25 per 10 hrs., and white foreman received $3. The cost was as follows per sq. yd.:

	Cts. per sq. yd.
Removing brick and concrete:	
Laborer, at $1.25	7.0
Foreman, at $3.00	1.2
Total	8.2
Relaying concrete:	
Laborer, at $1.25	7.9
Relaying brick:	
Laborer, at $1.25	4.5
Bricklayers, at $2.00	6.5
Bricklayers' helpers, $1.75	2.8
Total relaying brick	13.8

Materials:	
14 new brick, at 1½ cts.	21.0
0.12 cu. yd. sand, at $1.00	12.0
0.15 bbl. cement for concrete, at $1.20	18.0
Total materials	51.0
Summary:	
Removing brick and concrete	8.2
Relaying concrete	7.9
Relaying brick	13.8
Materials	51.0
Grand total	80.9

Cost of Laying a Stone Block Pavement, St. Paul.*—While granite block pavement is much less popular now than it was a few years ago, it is not likely that stone block pavements will disappear from use entirely for many years to come. This is particularly true of cities where sandstone of good quality is available for pavements. The Medina sandstone of central New York is a justly popular pavement for business streets. This sandstone is extremely dense and tough, having been partly metamorphosed until it is almost a quartzite. A very similar sandstone is found in Minnesota and is extensively used in St. Paul and Minneapolis.

Neither the Medina sandstone nor the Minnesota sandstone is open to the objection that may be raised against granite or trap rock blocks on the score of slipperiness. Both granite and trap rock wear smooth and glassy under traffic, and the corners of the blocks become rounded. But the sandstones just mentioned always remain gritty and never wear smooth, nor do the corners of blocks become rounded. In fact, when the joints are filled with Portland cement grout, a good sandstone pavement appears like one block of solid stone after it has been in use a while; yet it offers an excellent foothold for horses in spite of the apparent absence of joints. These facts are stated in justification of an article on a class of pavement which has been called out of date. It is altogether likely that New York City itself, which has tried and is still trying so many experiments with paving materials, will some day give Medina sandstone the trial that it deserves as a pavement for heavy traffic.

On the steep streets of Tacoma, Wash., sandstone block pavements are being laid, but the sandstone does not appear to be of as good a quality as Medina sandstone. Nevertheless it seems worth a trial, for asphalt is too slippery for such steep grades as are encountered in certain of the Tacoma streets.

Whatever may be the ultimate history of stone block pavements, it is evident that many city engineers and contractors will have to estimate the cost of laying such pavements, and for their benefit the following data are offered:

In the work to be described a base of Portland cement concrete

**Engineering-Contracting,* Oct. 3, 1906.

(1 : 3 : 6) was laid in the usual manner, and a sand cushion spread over the concrete. The sandstone blocks were hauled in wagons and tossed out into the street, instead of being piled on the sidewalk along the curb, as is often done. A considerable saving in the cost of laying is effected by throwing the stone blocks upon the concrete in advance of the paving gang, and a somewhat larger saving would be possible if dump wagons were used. If the street is about 40 ft. wide, the stone blocks are preferably piled in four long piles parallel with the curbs, as shown in Fig. 9. No attempt is made to stack the blocks up regularly, but they are merely tossed out of the wagons. A space is left between the piles so that strings can be stretched to guide the pavers in laying the blocks to grade.

To insure laying the pavement with the proper crown, three sight rods were made. Two of them were like T squares, made of a wooden leg ½ x 2 ins. with a crosspiece at the top. The other sight rod was made so as to telescope, as shown in Fig. 10, and had a leg about 1 in. square that was provided with a groove on one side for a distance 2 ft. below the crosshead. In this groove a 2-ft. rule was set, thus countersinking the rule so that its face was flush with the face of the leg. When this sight rod is extended so that the upper half of the 2-ft. rule is visible, the length of the rod is 4 ft., which is precisely the length of each of the other two sight rods. Before using the rods, a red or blue chalk line is struck with a chalked string on the face of each curb exactly at the finished grade of the pavement. Then at intervals along the curbs, paving blocks, B_1, B_5, B_6 and B_{10}, are temporarily set so that their upper faces are at grade. A sight rod is then held on each of the blocks, B_1 and B_5, at each curb, and the telescopic sight rod is held on a block, B_3, one-quarter of the distance across the street, as shown in Fig. 10. The telescopic leg of this sight rod is lowered enough to give the drop that secures the exact crown to the pavement shown in the specified cross-section, and the rod is clamped with the thumb screw. The paving block, B_3, is then raised or lowered until the tops of the three sight rods are exactly on line. Then paving blocks B_2 and B_4, are likewise put on grade; strings are then stretched from these blocks back to surface of the completed pavement. With these three strings to guide them, the pavers can readily lay the pavement exactly to grade. It is obvious that where paving materials are piled up in the street, it would be impracticable to use a straight edge from curb to curb, hence the necessity of some such method as the one just described.

On this particular piece of work each stone block averaged 6 x 6 x 9½ ins. and weighed nearly 30 lbs. A wagon load averaged 200 blocks, or 3 tons. Slat bottom wagons were used. This load was hauled over hard earth roads for much of the distance, and over the sand cushion on the concrete base.

The blocks were delivered in gondola cars, and unloaded from the cars into the wagon by two men, assisted by the driver. About half a wagon load (100 blocks) were tossed from the car into the

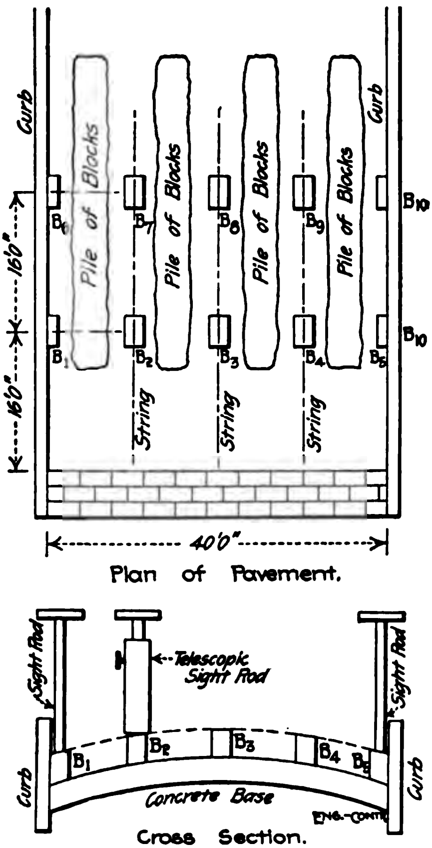


Fig. 9. Method of Laying Stone Blocks.

wagon box, the driver and the two men standing in the car. Then the driver would get into the wagon and pile up the rest of the blocks with some regularity as fast as the two men would pass them out to him. When the men were tossing the blocks into the wagon, each man averaged 14 blocks per minute when all he had to do was to stoop to pick up a block, but when it became necessary to walk to the opposite side of the car to get the blocks, each man would pick up and deliver only 7 blocks per minute. Under the latter condition the two men in the car would hardly keep the driver busy stacking up blocks in the wagon, yet a short-sighted foreman would have had one man in the wagon to each man in the car. With wagons coming along at regular intervals, the two men aided by the driver would load a wagon every 10 minutes.

In unloading the wagon on the street, one man and the driver consume about 5 minutes, each man tossing out 20 blocks per minute. To allow for slight delays in waiting for other wagons, etc., about 20 minutes should be taken as the average time consumed

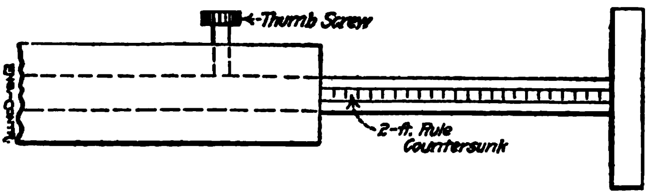


Fig. 10. Telescopic Sight Rod.

in loading and unloading the 200 blocks in each wagon. With wages of laborers at 20 cts. per hour, and team with driver at 45 cts. per hour, the fixed cost of loading and unloading (including lost team time) is 35 cts. per wagon load, or $1.75 per 1,000 paving blocks. The rule for determining the cost of loading, unloading and hauling is, therefore, as follows:

To a fixed cost of $1.75 per 1,000 blocks, add $1.80 per mile of distance between the car and the point of delivery on the street.

Since it takes about 20 of these paving blocks per square yard, we must divide the above figures by 50 to get the cost per square for loading and hauling. Then we have this rule:

To a fixed cost of 3½ cts. per square yard, add 3½ cts. more per square yard for each mile of distance between the car and the point of delivery on the street.

The above cost of hauling is based on team wages of 45 cts. per hour, a speed of 2½ miles per hour, and a 3-ton load.

The paving gang engaged in laying the stone blocks consisted of 3 skilled pavers and a helper, whose principal duty was to deliver sand wherever the sand cushion was not sufficiently thick. Each of the 3 pavers was paid 5 cts. per sq. yd. for laying the blocks. Consequently the work was rapidly done. There were no men engaged in ramming the blocks, but occasionally one of the pavers would

spend a few minutes ramming. Each of the three pavers averaged 70 sq. yds. per day of 10 hours, or 7 sq. yds. per hour, although as much as 85 sq. yds. per paver were laid in one day.

The joints between the blocks were grouted with Portland cement mortar mixed in the proportion of one bag of cement (1 cu. ft.) to one wheelbarrow of sand. The sand was not measured, but probably averaged about 2 cu. ft. to the wheelbarrow. The grout was mixed in a sheet iron tub, shaped somewhat like a long bathtub, about 18 ins. deep, 30 ins. wide, and 6 ft. long, provided with wooden strips (2 x 6 ins.) bolted to each side of the tub and projecting beyond the ends to serve as handles. The grouting gang was organized as follows:

1 man wheeling sand.
1 man carrying cement.
1 man carrying water.
3 men mixing grout with hoes.
2 men sweeping grout into joints.

These men averaged a batch of grout (about 2¼ cu. ft.) every 3 minutes, and a batch covered about 4 sq. yds. Hence a barrel of cement would cover about 16 sq. yds. With wages at 20 cts. per hour for laborers, the labor cost of grouting was 2 cts. per sq. yd. With sand at $1.00 per cu. yd. delivered, the cost of sand for grouting was 2 cts. per sq. yd.; and, with cement at $1.60 per bbl., the cost of cement for grouting was 10 cts. per sq. yd. After the grouting was completed a thin coat of sand was spread over the entire pavement, about 200 sq. yds. being covered by 1 cu. yd. of sand.

Summing up we have:

	Cts. per sq. yd.
Loading and unloading blocks	3½
Hauling blocks 1 mile	3½
Laying blocks, pavers, at 35 cts. per hr.	5
Laying blocks, helper, at 20 cts. per hr.	1
Labor, grouting, wages, at 20 cts. per hr.	2
Total labor	15
Add 10% for foreman, etc.	1½
Total	16½
Material for grout:	
1-16 bbl. cement, at $1.60	10
1-50 cu. yd. sand, at $1.00	2
1-200 cu. yd. sand (cover), at $1	½
Total	12½

The above does not include the concrete base nor the sand cushion between the base and the stone blocks.

Cost of Stone Block Pavement, Rochester, N. Y.—We have first to consider the dimensions of the blocks. When made of granite, they are split with wedges to tolerably uniform sizes; but when of stratified rock, like Medina sandstone, a carload of blocks will show wide variation in size of individual stone. In depth, of course, the blocks must be quite uniform, and 6 ins. depth is usually specified. In New York City 4 ins. is specified as the maximum

width of granite blocks, and it may be assumed as a certainty that they will not be found less than the maximum allowed, since to split them of less width out of granite would add materially to the cost per square yard. In Rochester, N. Y., 5½ ins. is specified maximum width for Medina blocks but, due to the thin stratification of the stone, they frequently come 3 ins. in width. The maximum length specified is usually 12 ins., the minimum 8 ins. Granite blocks which are quite uniform in size are sold by the 1,000, and sometimes by the square yard, laid. Medina blocks vary so in size that they are sold by the square yard.

Joints are ordinarily about ½-in. wide, and are filled first with gravel or sand, into which hot tar is poured. In New York City hot gravel is first poured in to the depth of 2 ins. and hot tar poured upon it till voids are filled; then another 2-in. layer of gravel and tar is added, and so on until the joint is full. By this method one-third to half the volume of the joints is tar. In Rochester the Medina sandstone joints are first filled clear to the surface with hot sand (damp sand will not run); then men with pointed wire pins like a surveyor's "stick-pin," used in chaining, force the sand down or pick it out if there is an excess, until the surface of the sand is 1½ to 2 ins. below the surface of the block pavement. Hot tar is then poured in and fills the upper 2 ins. of the joint without penetrating to the bottom. This method gives as good satisfaction, apparently, as the New York method.

In order to economize tar, which is quite an item, I would suggest a combination of the two methods; that is, first fill the joint with sand to within 2 ins. of the surface, then fill the upper 2 ins. with hot pea gravel (screened) and pour in tar.

Cement grout is used as a joint filler in some cities.

With blocks 3½ x 12 x 6 ins., there are 26 per sq. yd. where joints are ½-in. and the area of joints is 13% of the total area, and the volume of joint filler is nearly 0.6 cu. ft. per sq. yd. of pavement. If tar is worth 10 cts. a gallon, or 75 cts. a cu. ft., and one-third the volume of the joint is tar, the cost for tar alone will be $0.6 \times \frac{1}{3} \times 75 = 15$ cts. per sq. yd. of pavement, or 1½ gals.

Due to the fact that only one man helped the drivers load their wagons from the car, and only one man helped unload the wagons at the curb, the cost of loading and hauling was so excessive as not to be typical of what can be accomplished under good management, even where extra wagons are not used. Therefore, in the following summary of costs of this Rochester pavement I shall give the same costs for loading and hauling that appear on page 371.

The wagon load in the Rochester work averaged 2.7 tons.

After the blocks were stacked up at the sides of the street they were laid out on edge in the street in advance of the pavers, and assorted into sizes of uniform thickness, which laborers using wheelbarrows did at a cost of about 3 cts. a sq. yd. Two skilled pavers, with one laborer as a helper to supply stone, formed a gang. A paver laid 5 to 8 sq. yds. an hour; 6 sq. yds. per hr., or

60 sq. yds. per 10-hr. day, may be taken as an average for safe estimating, which, with pavers' wages at 30 cts. an hour and labor at 15 cts., makes cost of laying 6 cts. per sq. yd.

Following the pavers, come a gang of 3 men ramming and raising sunken stone, 1 screening sand for joints, 2 heating sand and tar, 1 wheeling sand for joints, 1 sweeping sand into joints, 7 poking sand down into joints and digging out excess, 5 filling upper 2 ins. of joints with tar, making a gang of 20 men following the pavers, and with wages at 15 cts. an hour, such a gang covering 60 yds. an hour, or 60 sq. yds. per day, makes the cost of ramming and filling joints 6 cts. a sq. yd. Summing up, we have for the total labor cost:

	Per sq. yd.
Loading and unloading	$0.035
Hauling 1 mile	0.035
Distributing blocks	0.030
Laying	0.060
Filling joints	0.060
Foreman, at 40 cts. per hr., 30 sq. yds.	0.013
2 water and errands boys	0.007
Total labor	$0.240

Cost of Medina block pavement:	Per sq. yd.
⅛ cu. yd. street excavation	$0.15
6-in. concrete foundation	0.50
1-18 cu. yd. sand cushion in place, at $1.08	0.06
Medina block (6-in.) f. o. b. Albion, N. Y.	1.15
Freight to Rochester	0.07
Unloading, hauling and laying	0.24
1.5 gals. tar at 10 cts. a gal.	0.15
1-50 cu. yd. sand for joints	0.02
Total	$2.34
Add for contractor's profit	0.26
Total contract price	$2.60

In paving four streets with Medina sandstone blocks, at Rochester, N. Y., the average amount of joint filler was 1.4 gallons of paving pitch per sq. yd.

The foregoing cost data apply to work done over large areas with fairly well organized gangs; but on small areas, such as paving gutters 3 ft. wide, I have had pavers average only 3½ sq. yds. per hour per paver, each paver securing his own blocks from piles along the curb.

By comparison with the cost of similar work done at St. Paul, described previously, it will be seen that this Rochester work was not as economically done. It should be noted, however, that in St. Paul a cement grout filler was used, while in Rochester the joint filler was tar.

Cost of Stone Block Pavement, Baltimore, Md.*—In 1908 there were 1,517 sq. yds. of Medina sandstone blocks laid by day labor forces for the city, replacing old wood blocks.

Wood blocks were removed from the tracks on Fayette St. from

**Engineering-Contracting*, Aug. 18, 1909.

Calvert to Charles streets, and also on Calvert street from Baltimore to Lexington street, and were replaced with Medina sandstone. The joints of the pavement were poured with Warren's Puritan brand block filler and followed with a covering of hot gravel. The itemized cost of the work was as follows:

	Per sq. yd.
Blocks	$2.350
0.0325 cu. yd. stone dust, at $1.20	0.039
0.02 cu. yd. screened gravel, at $1.90	0.038
41.9 lbs. filler, at $1 per cwt	0.419
1.3 lbs. coal, at $4 ton	0.003
Hauling	0.094
Labor	0.354
Total (1,517 sq. yds.)	$3.297

This high cost is characteristic of all the work done by the city forces in Baltimore.

Cost of Granite Block Pavement, New York.—Mr. G. W. Tillson, in "Street Pavements and Paving Materials," p. 204, gives the following data on the cost of granite block pavement in New York City in 1899. The day was 10 hrs. long:

Concrete gang:	Per day.
1 foreman	$ 3.00
8 mixers on two boards, at $1.25	10.00
4 wheeling stone and sand, at $1.25	5.00
1 carrying cement and supplying water, at $1.25	1.25
1 ramming, at $1.25	1.25
Total, 240 sq. yds. (40 cu. yds.), at 8.6 cts	$20.50

The concrete is shoveled direct from the mixing boards to place.

Cost 1 : 2 : 4 concrete:	Per cu. yd.
1⅓ bbls. natural cement, at $0.90	$1.20
0.95 cu. yd. stone, at $1.25	1.19
0.37 cu. yd. sand, at $1.00	0.37
Labor	0.51
Total	$3.27

With concrete 6 ins. thick this is equivalent to 54.6 cts. per sq. yd. for the concrete foundation.

The granite blocks were laid two days later with the following gang:

	Per day.
10 pavers, at $4.50	$ 45.00
5 rammers, at $3.50	17.50
6 chuckers, at $1.50	9.00
20 laborers, at $1.25	25.00
2 foremen, at $3.50	7.00
Total, 650 sq. yds., at 16 cts	$103.50

This is equivalent to 65 sq. yds. per paver per day.

	Per sq. yd.
Labor laying blocks, as above given	$0.16
22½ granite blocks, at $55 per M	1.24
3⅓ gals. paving pitch, at 7 cts	0.24
1⅓ cu. ft. gravel for joints, at $1.95 per cu. yd.	0.10
1½ cu. ft. sand for cushion, at $1.00 per cu. yd.	0.06
1 sq. yd. concrete, as above given	0.55
Total	$2.35

A gang laying granite block pavement on a 7-in. bed of sand was as follows:

	Per day.
4 pavers, at $4.50	$18.00
2 rammers, at $3.50	7.00
3 chuckers, at $1.50	4.50
3 laborers, at $1.25	3.75
Total, 280 sq. yds., at 12 cts.	$33.25

This is equivalent to 70 sq. yds. per paver per day.

	Per sq. yd.
Labor	$0.12
24 granite blocks, at $55 per M, delivered	1.32
0.2 cu. yd. sand, at $1	0.20
Total	$1.64

Apparently the labor cost of melting and pouring the pitch filler is included in work done by the 20 laborers.

Cost of Laying Granite Block Pavement, New York.*—The work was done in 1905 at 96th street. The paving was done by contract and was commenced Oct. 23, and finished Dec. 20 of the same year. The work consisted of laying 5,167 sq. yds. of granite block pavement on a 6-in. concrete base. The blocks used were 12 in. x 3½ in. x 7 in., and 116,250 of them were laid. The total number of lineal feet of joints that had to be tarred was 161,975.

In unloading and piling stone on the sidewalks the material was handled by the laborers by hand, the distance over which the stone was carried being but a few feet. It was found that each laborer unloaded and piled 1,390 blocks, or 62 sq. yds., per day.

The following was the labor cost, it being estimated that 22.5 blocks make 1 sq. yd.:

	Per sq. yd.
Unloading and Piling Blocks:	
0.016 day labor, at $1.75	$0.028
0.0006 day foreman, at $3.50	0.002
Total	$0.030
Excavating Old Pavement and 6 Ins. Earth:	
0.077 day labor, at $1.75	$0.135
0.0054 day foreman, at $3.50	0.019
Total	$0.154
Mixing and Laying Concrete Base:	
0.128 day labor, at 1.75	$0.225
0.008 day foreman, at $3.50	0.028
Total	$0.253
Paving and Tarring Joints:	
0.021 days pavers, at $4.00	$0.084
0.0175 days pavers' helper, at $2.00	0.035
0.0042 days rammers, at $4.00	0.025
0.0017 days spreading sand cushion, at $1.75	0.003
0.013 days filling joints with gravel, at $1.75	0.023
0.004 days pouring tar into joints, at $1.75	0.007
0.007 days tending tar and gravel kettles, at $1.75	0.012
0.002 days foreman, at $5.50	0.011
Total	$0.200

**Engineering-Contracting*, June 20, 1906.

It will be noted none of this work was done economically. The labor on the concrete, for example, was double what is commonly required under good management.

Each paver laid only 1,066 blocks, or 47½ sq. yds. per day, which is an equally miserable showing.

Cost of Granite Block Pavement, Baltimore, Md.*—This work involved laying 12,500 sq. yds. of granite block pavement on Light St., Baltimore, during Aug. 8 to Dec. 8, 1908. The work was not done by contract, but by city forces working by the day. The excessively high cost of the labor per sq. yd. adds another example to the invariable rule that it is cheaper to do such work by contract.

It is stated that during the 4 mos. one week was lost on account of bad weather and three weeks on account of the failure of the blocks to arrive on time. During a large part of the time, two 8-hr. shifts were worked daily. The Belgian blocks were quarried in Maine and shipped to Baltimore by boat, the first boat arriving Aug. 24. There were 24½ blocks per sq. yd., the price being $68.50 per M delivered on the line of the work.

The cost of the 6-in. concrete base was as follows, the mixture being 1 : 3½ : 6½ :

	Per cu. yd.	Per sq. yd.
Gravel, 1 cu. yd.	$1.10	$0.183
Sand, ½ cu. yd., at $0.72	0.36	.060
Cement, 4 bags	1.285	0.214
Total materials	$2.745	$0.457
Labor	0.786	0.131
Grand total	$3.531	$0.588

It is stated that an engineman, at $2.50 per 8 hrs., and 13 laborers, at $1.67, operated a ½ cu. yd. mixer (part of the time using a Ransome and part of the time using a Smith mixer), and the average 8 hrs. run was 333 sq. yds., or 56 cu. yds.; but the exceedingly high cost of $0.786 per cu. yd. for labor could not have occurred had the output averaged even the 56 cu. yds.

The average organization of the paving gang and the wages paid were as follows:

	Per 8 hrs.
1 foreman, at $4.00	$ 4.00
6 pavers, at $4.00	24.00
2 rammers, at $3.00	6.00
4 carts (including horse, cart and driver), at $2.50	10.00
7 pourers, at $1.75	12.25
16 laborers, at $1.66⅔	26.62
2 stone cutters, at $4.00	8.00
Total	$90.87

Special efforts were made to keep this gang constantly employed, and absolutely no time was lost by it other than delays

*_Engineering-Contracting_, Sept. 22, 1909.

occasioned by bad weather and failure of blocks to arrive on time. The concrete base at all times was kept well in advance of the pavers, experience having shown that the laborers would do better and quicker work when they could see an abundance of it ahead and no interruption. The average day's work complete for this gang was 267 sq. yds. or 44½ sq. yds. to the paver. This makes the cost 34 cts. per sq. yd., and does not include hauling the blocks from the boat to the street. This 34 cts. per sq. yd. is just about three times what it would cost a competent contractor, as will be seen by comparison with records above given.

It should be noted that the joints were filled with gravel and pitch, and that the labor of the 7 "pourers," being $12.25 per day, as above given, amounted to 4.6 cts. per sq. yd. It is stated, however, that the total labor cost of pouring was 5.75 cts. per sq. yd., from which it would appear that about 2 laborers (of the 16) were used to open barrels and keep the fires going, etc.

Coal, at $4 per ton, was used to melt the pitch and heat the gravel, and this wood cost ¼ ct. per sq. yd. of pavement. The tar kettle had a capacity of 2 tons, and was mounted on wheels. The gravel heater, also on wheels, had a capacity of 32 cu. ft. of gravel, but did not meet the requirements, so that two unmounted sheet iron pans (3½ x 7 ft.) were also used. It is stated that prior to the use of this tar kettle and the gravel heater, fuel (wood, at $5 per cord) had cost 1½ ct. per sq. yd.

Summarizing the cost, we have:

Materials:	Per sq. yd.
24½ granite blocks delivered on street, at $68 per M	$1.6900
0.083 cu. yds. stone dust for cushion (instead of sand), at $1.05	0.0875
0.039 cu. yds. gravel for joints, at $1.80	0.0700
48 lbs. tar for joints, at $0.01	0.4800
1¼ lbs. coal for heating tar and gravel, at $4.00 per ton	0.0025
Total materials	$2.3300
Labor:	
Heating and pouring filler and gravel	$0.0575
Other labor laying blocks	0.2675
Total	$2.6550
Concrete base (6-in.) as above given	0.5880
Grand total	$3.2430

This does not include removing an old pavement and grading.

The very high cost of the tar filler per sq. yd. is noteworthy. If it weighed 10 lbs. per gal., then there were 4.8 gals. per sq. yd., an altogether unnecessary amount.

After the final pouring of the tar (Warren's Puritan filler), the pavement was covered with hot gravel.

Cost of Dressing Old Granite Blocks, Baltimore, Md.*—Before lay-

*_Engineering-Contracting_, Sept. 22, 1909.

ing a new granite pavement on Light St., Baltimore, 6,500 sq. yds. of old granite blocks were taken up and relaid by city forces. The cost of laying the new blocks is given on page 377.

The following costs relate only to the dressing of the old blocks and relaying them. The costs were exceedingly high, due to the fact that the work was done by city forces.

Each man dressing old granite blocks averaged 253 blocks per 8-hr. day, and the cost was $13.16 per M, which indicates that the stonecutters received less than $3.30 per day. When relaid the labor cost was as follows:

	Per sq. yd.
Dressing and laying old blocks	$0.4325
Heating and pouring filler and gravel	0.0575
Total labor	$0.4900

For rates of wages and organization of the gang engaged in laying, see page 377.

Cost of Taking Up and Relaying a Cobble Stone Pavement.*—In repairing pavements, the costs of labor vary greatly, owing to the fact that the repair work is done in small patches and there is much time lost in the moving of tools from place to place as well as the time the men consume in moving. Records of these costs are exceedingly difficult to obtain, but we are fortunate in being able to give the cost of doing a repairing job that involved enough work to keep a repair gang busy for a day, so that some idea of the cost of the various labor items can be calculated.

The wages paid were as follows for an 8-hr. day:

Foreman	$4.50
Laborers	1.66
Pavers	5.30
Rammers	3.90
2-horse wagon and driver	5.00
Cart and driver	3.50

The work consisted of cobble stone paving, between the curb and a street car track, being 10 ft. wide and 104 ft. long. A 10-in. gutter of flag stones was laid 15 ins. from the curb; the intervening 15 ins. being laid with cobbles. In all there were 115.55 sq. yds. of paving, 9.55 sq. yds. of this being in the gutter, and 14.55 sq. yds. being between the gutter and the curb.

The system of carrying on the work was for three laborers to loosen the cobbles with bars, being followed by three laborers with picks, who piled the stones within reach of the pavers and kept the ground beneath the paving loosened with their picks. A wagon hauled ashes from the city stock pile to be used beneath the new paving, and it also hauled some cobbles from the yard that were needed. One laborer spread the ashes for the pavers.

One paver set the gutter and paved between the curb and the gutter. The curbing was not disturbed. This paver laid 24 sq. yds.

*_Engineering-Contracting_, Oct. 2, 1907.

in the day, more than one-third of it being gutter. The other three pavers did the rest of the laying, doing not quite 31 sq. yds. apiece. Two rammers rammed 106 sq. yds. of paving, being the entire amount less the gutter. The man who spread the ashes followed the rammers spreading sand over the work. The cart hauled the sand. At the close of the day the 7 laborers cleaned up in a few minutes.

The various labor items cost as follows:

Tearing up and handling stone:		
3 laborers with bars	$4.98	
3 laborers with picks	4.98	$ 9.96
Paving:		
1 laborer on ashes and sand	$ 1.66	
4 pavers	21.20	
2 rammers	7.80	30.66
Hauling materials:		
Cart sand	$3.50	
Wagon for ashes and stone	5.00	8.50
Superintendence		4.50
Grand total		$53.62

The cost per sq. yd. was:

Tearing up and handling stone	$0.086
Paving	.265
Superintendence	.040
Hauling materials	.073
Total cost per sq. yd.	$0.464

The cobble stones averaged about 8 ins. deep, hence the cost of tearing them up and stacking them was nearly 40 cts. per cu. yd.

Cost of Laying Asphalt Block Pavement, New York.*—In the upper part of New York City asphalt block pavements have been in use for many years and have steadily grown in popularity, particularly for residence streets. Formerly it was the custom to lay the blocks on edge, following the precedent of stone block and brick pavement construction; but within recent years the asphalt blocks have been laid flatwise, thus forming a wearing coat of asphalt blocks 3 ins. thick, each block being 3 x 5 x 12 ins. The old theory that a block pavement of any kind should be made of blocks set on edge is thus utterly overthrown, and it is not unreasonable to expect to see the time when paving bricks will also be laid flatwise, thus effecting a great economy in material. About five years ago the managing editor of this journal wrote an article setting forth the reasons why paving bricks of larger size, known as "blocks," should be laid flatwise instead of edgewise, but conservatism among city engineers is so strong that, so far as we know, not a single city has adopted the plan of laying paving brick flatwise.

Coming now to the method of laying asphalt blocks in New York City, we find another departure from precedent in that the venerable "sand cushion" has been abandoned. Of course a base of

**Engineering-Contracting,* Sept. 26, 1906.

concrete is provided in the usual manner, but, instead of laying a sand cushion on this base, it is now the practice to spread a thin coat of cement mortar on which the asphalt blocks are laid. This mortar coat is ½ in. thick, made of 1 part cement to 4 parts sand. It is mixed dry and wheeled onto the concrete in barrows, roughly spread with shovels and rakes and then leveled off with a wooden straight edge. To insure perfect leveling and the desired thickness of mortar, strips of wood ½ in. thick are laid at intervals of about 10 ft. Then two men shove a straight edge over these strips until the dry mortar is spread evenly. After this a man with a hose sprinkles the mortar until it is quite damp and ready to receive the asphalt blocks.

No attempt is made to bed the asphalt blocks down into the mortar, but they are merely laid firmly and given a rap with a hammer. In order to keep the courses of blocks in perfect line, a man with an ax follows the pavers and shoves over any parts of courses that are crooked by prying the blocks along with the ax blade shoved into the joint.

The blocks are loaded in wagons from boats or cars, hauled to the site of the work in advance of the concreting, and stacked in piles on the sidewalk along the curb. Asphalt blocks are not as tough as stone or brick and must be handled more carefully. In loading, as well as in unloading, one man tosses blocks to another man who stacks them up in the wagon, or on the sidewalk. About 300 blocks make a wagon load, and as each block weighs 18 lbs., a load is approximately 2.7 tons. In loading the blocks from gondola cars into wagons, it takes two men in the car to deliver blocks to one man in the wagon, who piles them up. With four men in the car and two men on the wagon (including the driver as one of these two men), 300 blocks are easily loaded in 10 minutes, even when the men in the car have to walk several steps to get each block. But when the blocks are merely picked up and tossed to the men in the wagon, these six men will load 300 blocks in 7½ mins. If the teams are in sufficient number for one team to arrive at the car every 10 mins., the 5 men (and the driver) load 1,800 blocks per hour. With wages of laborers at 20 cts. an hour, and team with driver at 45 cts., the cost of loading (including lost team time) is 80 cts. per 1,000 blocks, or 1.7 cts. per sq. yd.

Then the hauling costs $1.20 per 1,000 blocks per mile of haul from car to place of unloading, when 300 blocks form a load, speed of travel being 2½ miles an hour.

In unloading the wagon the driver and another man in the wagon toss blocks to two men on the sidewalk, who pile them up. These men unload 300 blocks in 7½ mins. without difficulty, but allowing 10 mins. for unloading, so as to include waits for wagons; we have a cost of 60 cts. for unloading each 1,000 blocks including the lost time of the team. Hence, to estimate the cost of handling and hauling, with wages as above given, use the following rule:

To a fixed cost of $1.40 per M for loading and unloading (including lost team time), add $1.20 per M for each mile of haul.

The organization of the gang laying the pavement (exclusive of the gang laying the concrete base), is as follows:

		Per hour.
4	pavers laying blocks, at 40 cts.	$ 1.60
16	men carrying blocks, at 20 cts.	3.20
1	man lining up blocks, at 20 cts.	.20
2	men splitting blocks, at 30 cts.	.60
1	man laying strips for straight edge, at 30 cts.	.30
7	men mixing mortar, at 20 cts.	1.40
6	men wheeling and spreading mortar, at 20 cts.	1.20
2	men raking mortar, at 20 cts.	.40
2	men leveling mortar with straight edge, at 20 cts.	.40
1	man sweeping sand into joints, at 20 cts.	.20
1	foreman, at 50 cts.	.50
42	men, total, 160 sq. yds., at 6¼ cts.	$10.00

This is equivalent to 40 blocks per paver per hr., or 360 per day.

This gang worked 9 hrs. daily, and when engaged in laying blocks averaged 180 to 200 sq. yds. per hr. There was no loafing on the part of the men who carried the blocks to the pavers, nor on the part of the pavers. But the 17 men mixing, wheeling and spreading mortar averaged only 23 cu. yds. of mortar placed per day, which is not a very good record.

The asphalt blocks were carried, two at a time, by hand, and were not delivered in wheelbarrows. They were laid to break joint by 4 ins., and this left a good deal of work to be done at the curbs in cutting at least two blocks to fill out each course. The two men splitting blocks for this purpose were unable to keep up with the paving gang. Hence, at intervals, the whole gang stopped paving and went back to assist in splitting blocks to close the courses, and to fill the joints of the blocks with sand.

No cement is mixed with this sand filler, but loads of dry sand are hauled onto the pavement, dumped, spread, and swept into the joints. A cubic yard of sand fills the joints of about 200 sq. yds. of block pavement.

The time required to spread the sand filler and fill out the courses, when included with the time actually spent in laying reduced the average output to 160 sq. yds. per hour, making a cost of 6¼ cts. per sq. yd. for laying the mortar and blocks and filling the joints with sand. Wages actually paid were somewhat lower than those above given, being $1.50 for 9 hours for laborers and $2.50 to $3.00 for pavers. The pavers did not belong to a union.

It will be noted that each of the 4 pavers averaged 45 sq. yds. per hour when not engaged in cutting and fitting blocks at the end of courses, and, as a matter of fact, on the best day each paver averaged 55 sq. yds. per hour, or 495 sq. yds. per day.

To the contractor who has been used to laying stone block pavement only, these records may seem erroneous. Even the brick paving contractor may be inclined to doubt their accuracy. It should be remembered, however, that one asphalt block covers 5 x 12, or 60 sq. ins. of surface, and that it takes only 21 asphalt blocks per square yard, as compared with two or three times that number of paving bricks or blocks.

The time consumed in selecting stone blocks and in bedding them in the sand cushion materially reduces the output of the pavers compared with asphalt-block work.

Cost of Asphalt Block Pavement, Baltimore.*—This work was done in 1908 by city day labor forces, and, as is usual in such cases, the cost was high. An 8-hr. day was worked, wages being as given on page 377.

Nearly 30,000 sq. yds. were laid in 1908, some of it on a concrete base, of which the following is a typical cost where the concrete was 6 ins. thick, the stone dust cushion being 1 in. thick, and the asphalt block wearing coat being 3 ins. thick. The blocks were 3 x 5 x 12 ins.

	Per sq. yd.
1-6 cu. yd. concrete base, at $3.60	$0.600
0.07 cu. yd. stone dust, at $1.20	0.084
20.7 asphalt blocks, at $65 per M	1.340
Labor laying blocks	0.220
Total	$2.244

Cost of Creosoted Wood Block Pavement, Minneapolis.*—Minneapolis was among the first cities in the United States to lay creosoted wood block pavement to any extent. At the end of 1902 the city had over 200,000 sq. yds.* of this type of pavement, and since then this yardage has been largely increased. Minneapolis was also probably the first city to use blocks made of Norway pine and tamarack to any considerable amount.

The following figures show the actual average detailed cost of about 145,000 sq. yds. of pavement constructed in various parts of Minneapolis in 1908. The figures were obtained from pay rolls, bills of materials and estimates and are the actual cost for labor and materials for constructing the pavement.

The average unit cost per square yard for the 145,000 sq. yds. of creosoted wood block pavement was as follows:

	Per sq. yd.
Removing old cedar paving	$0.0270
Grading	0.1320
Concrete base (labor and materials)	0.5226
Cushion sand, at $0.60 per cu. yd.	0.0200
Creosoted paving blocks (f. o. b. Mpls.)	1.3900
Hauling blocks	0.0450
Laying blocks	0.0590
Hauling cement	0.0090
Paving pitch filler, at 5.7 cts. per gal.	0.0570
Hauling pitch for filler	0.0100
Labor on filler	0.0120
Asphalt filler along St. R. R. tracks	0.0029
Headers (plant)	0.0030
Sand on finished paving	0.0100
Tools	0.0200
Rolling	0.0100
Cleaning up finished street	0.0050
Miscellaneous materials	0.0030
Miscellaneous labor	0.0100
Total	$2.3475

**Engineering-Contracting*, Aug. 18, 1909.

Summarizing the labor items of laying the wood block pavement, we have:

	Per sq. yd.
Laying blocks	$0.0590
Labor on pitch filler	0.0120
Rolling	0.0100
Cleaning up	0.0050
Total	$0.0860
Hauling blocks	0.0450
Miscellaneous labor	0.0100
Grand total	$0.1410

This does not include labor of removing old pavement and grading.

The organization and wages of the gang directly engaged in laying the blocks were about as follows:

	Per day.
6 pavers, at $2.50	$15.00
6 helpers setting up blocks, at $2	12.00
7 wheelers, at $2	14.00
4 sand cushion men and sweepers, at $2	8.00
2 sand cushion men and sweepers, at $2.25	4.50
2 sand cushion men and sweepers, at $2.50	5.00
1 grader, at $2.25	2.25
1 water boy, at $1.20	1.20
Total (1,050 sq. yds.)	$61.95

This gang averaged about 1,050 sq. yds. per 8-hr. day for the full season's work. This included waits for material at times and delays for other causes. Some days the gang laid as high as 1,400 sq. yds.

The detailed cost of the concrete base was as follows:

	Per sq. yd.
Crushed limestone, at $1.65 per cu. yd	$0.2186
Sand, at $0.60 per cu. yd	0.0374
Cement, at $1.12 per bbl	0.1122
Labor	0.1303
Street railway concrete	0.0241
Total	$0.5226

The above figures include, of course, a number of items peculiar to the city, which might not obtain in another community. For instance, the first item—removing old blocks (cedar) happens only in a few streets, but yet amounts in total to enough materially to affect the cost price and must be considered. Also in the detailed cost of the concrete, there is included an item for street railway concrete. This item would not appear elsewhere, but is a very considerable one in Minneapolis. The street railway company maintains paving from the outer edge of the rails in one track to the outer edge of the rail in the other track, and does not include the ties extending beyond the rail, 1½ ft. in each case, and for convenience to them and to the city, the railway company puts in the concrete base from the rail to end of the tie at the same time it puts

in the concrete for the tracks, the city paying the company for it. This constitutes the item of "street railway concrete." An item of "headers" also is included. This is a 4 x 10-in. plank set on edge at the returns on unpaved streets to protect the edge of the new paving.

The cost varies in different localities in the city, there being as much as 25 cts. per square yard difference. This is due to difference in length of hauls for materials, difference in the grading and from other local conditions.

The concrete is mixed by hand. It is 5 ins. thick and is mixed in the proportion of 1:3:7. The stone used in 1908 was a crushed limestone, costing on an average $1.65 per cu. yd., on the basis of $1 per cu. yd. at the crusher, the city doing the hauling. The cement cost $1.12 per barrel f. o. b. Minneapolis, and the mason sand for concrete cost on an average 60 cts. per cu. yd.

The filler used in the work was distilled from coal tar and was furnished by the Barrett Manufacturing Co. It was brought on the streets in hot tanks. The season's work averaged about 10 lbs. of pitch filler to the square yard of finished pavement. This is a little less than one gallon to the yard.

The sand cushion was 1 in. thick and the fine sand used cost on an average 60 cts. per cu. yd.

The blocks used were Norway pine and tamarack, 4 ins. thick, and were treated with 16 lbs. of oil to the cubic foot.

Common labor was paid at the rate of $2 per day, teams were paid $4 per day, block layers $2.50 per day, and a few special men from $2.25 to $2.50 per day. An 8-hr. day was worked.

All the work was done by force account under the direction of B. H. Durham, street engineer, to whom we are indebted for the above information.

Labor Cost of Creosoted Wood Block Pavement at Seattle.*—The following data abstracted from the "Pacific Builder and Engineer" show the labor cost of constructing some creosoted wood block pavement on 4th Ave. in Seattle. The blocks had a cross-section of 3 x 4 x 8 ins. and were made from selected Western Washington fir stock. They were treated by the Pacific Creosoting Co. at its Eagle Harbor works. The sub-base for the pavement consisted of 6 ins. of concrete, on which was placed a 1-in. cushion of cement and sand mixed 1:3, spread and sprinkled.

During one day's work 322 sq. yds. of the pavement were laid, the organization of the gang and wages being as follows:

	Per day.
16 laborers, at $2 per day	$32.00
1 paver, at $5 per day	5.00
Superintendent, at $5 per day	5.00
Total, 322 sq. yds., at $0.1303	$42.00

*Engineering-Contracting, Aug. 4, 1909.

This gang mixed the grout, spread it and laid the blocks at the following cost:

	Per sq. yd.
Laborers	$0.0993
Pavers	0.0155
Superintendent	0.0155
Total	$0.1303

The concrete base cost 90 cts. per sq. yd. by contract. Sand cost $1.25 per cu. yd. delivered, and cement was $2.25 per bbl. delivered. About 4,000 sq. yds. of pavement was constructed.

It should be noted that there was an unnecessarily large number of laborers (16) to one paver.

Cost of Creosoted Wood Block Pavement, Holyoke, Mass.*—The following work was done in 1906, by day labor, under the supervision of Mr. James L. Tighe, city engineer. About 5,500 sq. yds. of wood blocks were laid on a 5-in. concrete base, the concrete being a 1:3:6 mixture. The 1-in. cushion coat was a 1:7 mixture. An 8-hr. day was worked. The organization of the gang for excavating, concreting and paving with blocks was as follows:

	Per day.
Excavation:	
1 steam roller and engineman hauling plow	$ 10.00
4 men on plow, at $2.00	8.00
20 men loading earth, at $2.00	40.00
4 teams hauling (¾ mi.), at $4.00	16.00
2 men finishing subgrade, at $2.00	4.00
Total excavation	$ 78.00
Hauling Stone and Sand:	
6 men loading stone from cars, at $2.00	$ 12.00
2 teams hauling stone, at $4.00	8.00
3 men loading sand in pit, at $2.00	6.00
2 teams hauling sand (0.8 mi.), at $4.00	8.00
Total hauling broken stone and sand	$ 34.00
Mixing Concrete:	
20 men mixing and placing by hand, at $2.00	$ 40.00
Paving:	
4 men mixing and placing cement cushion, at $2.00	$ 8.00
2 pavers laying blocks, at $2.00	4.00
6 pavers' tenders, at $2.00	12.00
1 man spreading sand over pavement, at $2.00	2.00
Total paving	$ 26.00
Supervision:	
2 foremen, at $3.10	$ 6.20
1 superintendent	5.00
Total supervision	$ 11.20
Grand total labor	$189.20

**Engineering-Contracting,* May 13, 1908.

This gang excavated earth and laid 300 sq. yds. per 8-hr. day, hence the labor cost was:

	Per sq. yd.
Excavation	$0.260
Hauling broken stone and sand	0.113
Mixing and placing 5-in. concrete	0.133
Paving	0.087
Supervision	0.037
Total	$0.630

The cost of the concrete materials was about as follows:

	Per sq. yd.
0.14 cu. yd. broken stone for concrete, at $1.20	$0.17
0.07 cu. yd. sand (pit royalty), at $0.10	0.01
0.14 bbl. cement for concrete, at $1.67	0.24
Total materials for concrete	$0.42

We have the following cost:

Materials for Wearing Coat:	Per sq. yd.
54 creosoted blocks, at $3.95	$2.140
0.03 bbl. cement for mortar cushion, at $1.67	0.050
0.03 cu. yds. sand for mortar cushion, at $0.55	0.017
Total materials for wearing coat	$2.207
Labor on Wearing Coat:	
Men on cement cushion	$0.027
Pavers laying wood blocks	0.013
Pavers' tenders	0.040
Man spreading sand over blocks	0.007
Supervision, 6% of labor	0.005
Total labor on wearing coat	$0.092
Concrete Base:	
Materials for 5-in. concrete base	$0.420
Labor on concrete base, incl. 6% for supervision	$0.140
Total, excluding grading	$2.859
Grading, incl. 6% for supervision	0.276
Grand total	$3.135

Life of Wood Block Pavement.*—Mr. William Weaver gives the following English data:

Wood paving has received my special attention since 1872, when it came into extended use.

In Kensington, May, 1882, I had laid experimental areas of creosoted wood blocks, respectively 3 ins., 4 ins. and 5 ins. deep, jointed in different ways, and as the result of careful observation, I advised my board to lay 4-in. creosoted deal blocks in Sydney place, an omnibus route leading from Fulham road to South Kensington station. These blocks were laid close, and grouted first with pitch and then with Portland cement, the work being carried out in November, 1889, and the blocks lasted until June, 1901, when the road was repaved in a similar manner.

The conclusion at which I have arrived, after my experiments initiated in 1882, was that creosoted deal furnished the most

**Engineering-Contracting,* Sept. 15, 1909.

suitable and economical road pavement; further, that 5-in. blocks lasted as long as 6-in., and that 4-in. creosoted blocks answered all the requirements of roads where the traffic is not excessive. In order to understand that a 5-in. will last as long as 6-in. paving, it must be borne in mind that wood paving must be renewed as soon as its general surface ceases to drain itself; and this happens when the blocks forming the haunches of the road are reduced between 1 in. and 2 ins. in depth, the channel or watercourse meanwhile not being exposed to similar traffic, suffer no diminution of depth.

The above conclusions are fully borne out by Table XIV of instances, extracted from my annual reports, which furnishes details of 304,220 yds. of 5-in. and 137,164 yds. of 4-in. wood paving laid in Kensington since 1887.

In connection with that list, an instructive comparison is furnished by the history of the wood laid in the Hammersmith road in continuation westward of the area laid in Kensington; at the same time (May, 1886), Hammersmith laid down 6-in. plain deal blocks which lasted a little over six years, being replaced in July, 1892, with 5-in. jarrah blocks. After eight years the jarrah blocks were reversed and rebedded in July, 1900, and replaced with 5-in. creosoted deal in July, 1903. The 5-in. creosoted deal adjoining in Kensington, laid in May, 1886, lasted until September, 1901, equal to the combined lives (less two years) of the plain deal with jarrah together.

Further, with regard to the above schedule, I may add that all the roads enumerated are omnibus routes, but the traffic on each, of course, varies in severity.

In conclusion, I would point out that by reducing the depth of the wood (each inch of reduction means over a shilling per yard saved), and, further, by about doubling the life of the wood by creosoting, wood paving need no longer be considered an expensive luxury, but must be regarded as a sanitary and economical substitute for macadam, where costing over 8d. per yard annually to maintain. At the same time it must not be lost sight of that such substitution has a tendency to increase the rateable value of the abutting property, owing to the improved appearance, cleanliness and quietude of the road.

Cost of Asphalt Pavement in California.*—Through the kindness of Mr. Charles Kirby Fox, C. E., we are enabled to give the costs of two asphalt paving jobs in a Southern California city.

The first piece of work was done under a Vrooman act contract, the contract price being $1.89 per sq. yd. It consisted of the construction of pavement on two blocks of street. The street was 48 ft. wide, had 2½ ft. concrete gutters, a rise of 6 ins. to 8 ins. and a grade of 1 per cent. It drained well and there were no water holes. The pavement consisted of a 5-in., 1 : 3 : 6 concrete base, a 1-in. binder course and a 2-in. asphalt wearing surface.

*_Engineering-Contracting_, April 1, 1908.

TABLE XIV.

Name of road.	Sq. yds.	Description of wood.	Date when laid.	Life of wood years.
Westbrourne grove and Archer street	10,328	5-in. creosoted deal	Dec., 1887	20
		5-in. naphthalized blocks*	Dec., 1887	10.42
		5-in. plain deal*	Dec., 1887	6
		5-in. blocks dipped in creosote*	Dec., 1887	10.42
Kensington High street	1,714	4-in. jarrah	Oct., 1892	6.92
		4-in. creosoted deal	Sept., 1899	7
		4-in. red gum (American)*	Sept., 1899	3
Kensington road, between Honton street and Russell road	16,550	5-in. creosoted deal	Mar., 1890	11.5
Kensington road, from Russell road to western boundary	1,528	5-in. creosoted deal	May, 1886	15.3
Brompton road	13,183	5-in. creosoted deal	Sept., 1893	10.08
Old Brompton road	25,307	5-in. creosoted deal	Oct., 1891	13
	3,209	4-in. jarrah	Oct., 1891	8
Pembridge Villas	6,542	5-in. creosoted deal	May, 1895	Still down
		5-in. jarrah*	May, 1895	8.16
		5-in. karri*	May, 1895	8.16
		6-in. red gum (Australian)*	May, 1895	9.60†
		6-in. Jodolized deal*	May, 1895	9.60†
Holland Park avenue	18,846	5-in. creosoted deal	Oct., 1892	14
Sydney place	3,509	4-in. creosoted deal	Nov., 1889	11.60
Cromwell road	16,504	4-in. creosoted deal	Oct., 1900	Still down
Holland road	16,160	4-in. creosoted deal	June, 1899	Still down

*Trial sections under equal conditions of traffic. †Extensively patched in 1903.

Grading.—The grading cost $0.1233 per sq. yd. and was done by the following organization:

	Per day.
1 foreman, at $5	$ 5.00
1 timekeeper, at $3	3.00
1 engineman, at $3, part time on steam roller and part time on plowing	3.00
2 teams plowing, at $4	12.00
6 teams hauling, at $4	24.00
14 laborers shoveling, at $2	28.00
Total, 610 sq. yds.	$75.00

Concrete Base.—The 5-in. concrete base was made of a 1:3:6 mixture. On Job No. 2 it was found, however, that these proportions did not work well, as all the voids were not filled, and that a 1:3:5 or 1:4:6 mixture made a better concrete. The concrete was hand mixed on two 7 x 7-ft. boards, in the following manner: First, the sand and cement were dumped on the board and hoed across and wet; then the stone was dumped on the mortar and the whole mess pulled back and forth across the boards and set on the ground in about the place it was to occupy. In the meantime the other board was being filled up and the operation repeated, the first board being pulled a little forward and refilled. The concrete secured was fair. The cost of mixing and placing the concrete was as follows:

	Per cu. yd.	Per sq. yd.
0.93 bbl. cement, at $2.50	$2.28	$0.316
0.45 cu. yd. sand, at $0.80	0.31	0.043
0.9 cu. yd. stone, at $2.00	1.80	0.250
Tools and water	0.12	0.016
Labor and superintendence	1.20	0.166
Total	$5.71	$0.791

The wages and organization of the gang engaged in mixing and placing the concrete base were as follows:

	Per day.
1 superintendent, at $5	$ 5.00
1 timekeeper, at $3	3.00
2 laborers, at $2, wheeling sand	4.00
3 laborers, at $2, wheeling stone	6.00
6 laborers, at $2, mixing	12.00
1 laborer, at $2, tending water	2.00
2 laborers, at $2, leveling and spreading	4.00
1 laborer, at $2, tamping	2.00
Total, 31.7 cu. yds., at $1.20	$38.00

The tools used were as follows:

Two 7 x 7-ft. mixing boards, 7 wheelbarrows, 12 picks, 12 shovels, 6 hoes, 300 ft. of hose, 1 tamper, 12 lanterns and 1 tool box.

Binder.—The 1-in. binder course cost as follows:

	Per sq. yd.
Asphalt, at $20 per ton	$0.063
Binder stone, at $2 per cu. yd.	0.081
Labor and plant	0.045
Total	$0.189

The 2-in. asphalt wearing surface was mixed in a plant having a capacity of 8 cu. ft. The tools used in connection with the wearing surface work consisted of a 2½-ton (30-in.) roller, a 300-lb. hand roller, a fire pot, 2 Watson wagons, 2 smoothers, 6 tampers, 6 shovels, 2 dirt picks, 6 asphalt picks, 3 rakes, 5 brooms and 4 wheelbarrows.

The cost of the 2-in. asphalt wearing surface was as follows:

	Per sq. yd.
Asphalt, at $20 per ton	$0.198
Sand, at $1 per cu. yd.	0.045
Dust, at $10 per ton	0.090
Labor	0.090
Plant	0.198
Total	$0.621

The high plant charge of 19.8 cts. was due in part to the mixing plant. This occupied two cars. In addition the job was very small, consisting of two 330-ft. by 46-ft. blocks.

The wages and organization of the gang engaged in the wearing surface work were as follows:

	Per day.
Superintendent, at $5	$ 5.00
Timekeeper, at $3	3.00
1 engineman, at $3.50	3.50
1 mixer, at $3	3.00
1 mixer helper, at $2.50	2.50
1 mixer dipper, at $2.50	2.50
2 men shoveling to heater, at $2.00	4.00
3 men wheeling, at $2	6.00
2 teams hauling to streets, at $4	8.00
2 rakers, at $3	6.00
3 shovelers, at $2.50	7.50
1 smoother, at $2.00	2.00
1 tamper, at $2.10	2.10
2 roller men, at $2.50	5.00
1 engineman on roller, at $3.50	3.50
1 man sweeping, at $2	2.00
Total	$65.60

The second piece of work was done in the fall of 1907 by private contract, at a contract price of $1.89 per sq. yd. The work consisted of the construction of pavement on five blocks of streets and four alleys. The streets were 48 ft. wide, had a rise of 6 ins., and a grade of 1 per cent; they had no gutters. The alleys were 20 ft. wide and had a grade of 0.4 per cent to 1 per cent. The alley that had a 1 per cent grade drained well, but those where grade was less had to be ironed out. The alleys had no gutters. Experience in the city where this pavement was laid has shown that if the gutters fall more than ⅛ in. to the foot they can be made to drain by using the straight edge. If the fall is less than ⅛ in. there will be water holes. Where the gutter has to be raked it was found advisable to have double the fall per foot. The pavement consisted of 4-in., 1:3:6 concrete base, a 1-in. binder course and a 2-in. wearing surface.

Grading.—The grading was done by another contractor and cost $0.099 per square yard, the work being done by the following force:

	Per day.
1 foreman, at $3	$ 3.00
½ timekeeper, at $3	1.50
1 engineman, at $3, part time on steam roller and part time plowing	3.00
2 teams plowing, at $4	8.00
8 teams hauling dirt away, at $4	32.00
18 laborers shoveling, at $2	36.00
Total	$83.50

Concrete Base.—The concrete base was laid by the contractor who did the grading. The concrete was mixed in a Ransome mixer, a 3 cu. ft. barrow of sand being dumped into the mixer first, then 1 cu. ft. of loose cement and finally two barrows of stone. After several turns of the mixer the mass was discharged and taken in scoops by the laborers and put in place. Two laborers spread the mixture, two laborers leveled it, and two more laborers tamped it. The mixture was as wet as it could be without the mortar running from the stone. Each wheelbarrow man had two helpers. The gang usually consisted of 28 men; 42 men were the most that could be used to advantage. The concrete on this job was better than that on the first job. The cost of the 4-in. concrete base was as follows:

	Per cu. yd.	Per sq. yd.
0.95 bbl. cement, at $3.00	$2.85	$3.16
0.45 cu. yd. sand, at $0.80	0.31	0.034
0.91 cu. yd. stone, at $2.00	1.82	0.202
Labor and superintendence	0.974	0.108
Rent of machine, repairs, oil	0.246	0.027
Total	$6.20	$0.687

The stone used in the concrete was hauled from cars about ½ mile distant, the cost of unloading and hauling being as follows:

	Per cu. yd.
Foreman, at $3	$0.03
Laborers, at $2	.15
Teams, at $4	.19
Total	$0.37

This cost is included in the $2 in the table.

The wages and organization of the force engaged in mixing and placing the concrete base were as follows:

	Per day.
1 foreman, at $100 per month	$ 4.00
1 engineman on mixer, at $3.50	3.50
1 handyman, at $2.50	2.50
1 team, at $4	4.00
1 laborer tending mixer discharge, at $2	2.00
2 laborers carry and measure cement, at $2	4.00
1 laborer at $2 wheeling sand, and 1 laborer at $2 helping	4.00
2 laborers at $2 wheeling stone, and 2 laborers at $2 helping	8.00
2 laborers dumping concrete, at $2	4.00
2 laborers tamping, at $2	4.00
9 laborers taking concrete from machine, at $2	18.00
Total, 60 cu. yds	$58.00

These concrete men evidently worked with no energy, as is shown by their miserably small output with a good plant.

The plant used consisted of a Ransome concrete mixer with 6 h.p. gasoline engine mounted on wheels, one 1 cu. ft. cement box, four 3 cu. ft. wheelbarrows, 29 scoops, 12 short-handled shovels, 18 long-handled shovels, 12 picks, 400 ft. of hose, three tampers, 12 lanterns and one tool box.

Binder.—The stone used in the binder had the dust screened out and was passed through a 1¼ in. screen. It was found, however, that this did not leave enough fine stuff, pea size or thereabouts, so screenings from the sand were taken and from this was screened out all particles above 1 in. in size. One part of these screenings was mixed with two parts of broken stone and heated to 200° F. Four cubic feet of this was mixed with 27 lbs. of melted asphalt, making a strong binder. The cost of the binder was $0.171 per square yard.

The wearing surface was mixed in batches of the proportion of 4 cu. ft. of sand, heated to about 300° F., 30 lbs. of cold dust, and 50 lbs. of melted asphalt. These were mixed very thoroughly, usually taking 1¼ minutes to the batch. The mixture usually arrived on the street at about 280° F. It was found that a 4 cu. ft. batch would lay about 20 sq. ft. of 2 in. surface. The cost of the wearing surface was $0.549 per square yard.

The wages and organization of the force engaged in preparing and laying the binder and the wearing surface were as follows:

	Per day.
Superintendent, at $120 per month	$ 5.00
1 engineman, at $3.50	3.50
1 mixer, at $3.00	3.00
1 mixer helper, at $2.50	2.50
1 heater, at $2.50	2.50
1 man shoveling sand and 1 man shoveling marble dust, at $2.50	2.50
1 scraper team, at $4.00	4.00
2 teams hauling to street, at $4.50	9.00
1 engineman on roller, at $3.50	3.50
2 rakers, at $3.00	6.00
2 shovelers, at $2.50	5.00
2 hand roller men, at $2.50	5.00
2 tampers, at $2.50	5.00
Total	$56.50

The plant used consisted of a 4 cu. ft. mixer, a 5 ton (38 in.) roller, a 500 lb. hand roller, a fire pot, 3 Watson wagons and teams, a scraper, 3 rakes, 3 shovels, 2 tampers, 3 smoothers, 1 asphalt pick and 2 brooms.

Summary.—A summary of the costs of the two jobs is as follows:

	Job 1. Per sq. yd.	Job 2. Per sq. yd.
Grading	$0.128	$0.099
Concrete	0.791	0.687
Binder	0.189	0.171
Surface	0.621	0.549
Office, collection and general expense estimated	0.180	0.180
Total	$1.904	$1.686

Job 2 had more material and better workmanship per unit than Job 1. It was better managed, especially in the asphalt department. Job 1 had an asphalt mixer requiring two cars to move, while on Job 2 the mixer required but one car, but it cost more to move the latter. The small plant was the most economical. On concrete work the lost time of steady pay men when they were not mixing amounted to about 10 cts. per cubic yard; usually, however, when these men were not mixing they were engaged on other work.

Cost of 77,200 Square Yards Asphalt Pavement.*—Mr. F. E. Puffer gives the following:

The cost of laying 77,208 sq. yds. of asphalt pavement in an eastern city, which was a season's work, was as follows:

The price paid for common labor was $1.50 a day, and $5 a day for team and driver.

	Per sq. yd.	Total Per sq. yd.
Grading street:		
Sundries	$0.021	
Labor	0.204	
Teams ($5 a day)	0.087	$0.312
Concrete base (6-in.):		
0.173 bbl. natural cement, at $0.83	$0.144	
0.055 cu. yd. sand delivered, at $0.98	0.054	
0.176 cu. yd. stone delivered, at $1.62	0.285	
Sundries	0.015	
Labor laying	0.094	
Labor, general	0.001	$0.593
Binder (1½ ins.):		
Materials	$0.188	
Fuel	0.016	
Tools and sundries	0.001	
Labor, yard (mixing, etc.)	0.026	
Labor, laying	0.023	
Labor, general	0.001	
Teams, hauling ($5 a day)	0.024	$0.279
Surface (2-in.):		
Materials	$0.645	
Fuel	0.022	
Tools and sundries	0.054	
Labor, yard (mixing, etc.)	0.053	
Labor, laying	0.047	
Labor, general	0.028	
Teams, hauling	0.035	$0.884
General expense:		
Salaries	$0.018	
Rent and expenses	0.014	
Plant, etc.	0.025	$0.057
Grand total		$2.125

The exact proportions of the materials used in the binder and in the surface coats are not available, but the prices paid for materials and supplies were as follows:

Binder stone, per cu. yd.	$ 1.00
Asphalt, per ton	50.75
Petroleum residuum, per gal	.07⅝
Sand, per cu. yd.	.65
Pulverized limestone, per ton	3.50
Coal (anthracite) used in dryers, per ton	3.00
Coal (soft) used under boilers, per ton	2.85
Wood to heat asphalt tanks, per cord	4.00

**Engineering-Contracting*, Feb. 5, 1908.

It will be noted that the cost of the asphalt was much higher than it is at present, the present price being about $30 a ton. Since there are about 4 lbs. of asphalt per sq. yd. of binder, and about 19 lbs. per sq. yd. of surface coat, the difference of $20 a ton (or 1 ct. per lb. of asphalt) would reduce the above given costs by 4 cts. per sq. yd. of binder and 19 cts. per sq. yd. of surface coat.

An old plant having a value of about $22,000 was used. The plant repairs amounted to $1,525, or 2 cts. per sq. yd., which is unusually low. Ordinary plant charges are about 7½ cts. per sq. yd. where a modern plant is used, but in such cases the labor cost is lower than in this case. I have made no allowance for interest on and depreciation of plant.

The fallacy of attempting to estimate the cost of asphalt pavements from a single day's operation is clearly shown by comparing the records of costs on different jobs extending over considerable periods of time. Marked differences of cost occur, arising partly from variations in local conditions, and partly from the varying efficiency of the workers, and partly from the exactions of the inspector.

The following are the costs of three different streets, showing how costs vary.

Contract A was performed under favorable weather conditions on a suburban street, close to the source of supply of concrete materials and far from the paving plant. The cost was a little below the season's average above given:

CONTRACT A.
(3,284 sq. yds.)

	Per sq. yd.	Total Per sq. yd.
Grading street:		
Sundries	$0.019	
Labor	0.123	
Teams	0.089	$0.231
Concrete base (6-in.):		
Natural cement, at $0.866 per bbl	$0.138	
Sand, at $0.92 per cu. yd.	0.051	
Stone, at $1.77 per cu. yd.	0.295	
Sundries	0.015	
Labor	0.093	$0.592
Binder (1½-in.):		
Materials	$0.192	
Fuel	0.011	
Tools and sundries	0.002	
Labor, yard	0.024	
Labor, laying	0.024	
Teams hauling	0.024	$0.277
Surface (2-in.):		
Materials	$0.673	
Fuel	0.026	
Tools and sundries	0.055	
Labor, yard	0.047	
Labor, laying	0.042	
Labor, general	0.029	
Teams hauling	0.035	$0.907
General expense	$0.042	$0.042
Grand total		$2.049

Contract B was the last contract of the season. Weather was unfavorable but not severe. Length of haul was less than the average for the season. The forces, except asphalt, were somewhat demoralized by the fact that the job would soon end. The cost was naturally high.

CONTRACT B.
(5,278 sq. yds.)

	Per sq. yd.	Total Per sq. yd.
Grading street:		
Sundries	$0.021	
Labor	0.138	
Teams	0.129	$0.288
Concrete base (6-in.):		
Cement, at $0.845 per bbl.	$0.142	
Sand, at $1.18 per cu. yd.	0.063	
Stone, at $1.93 per cu. yd.	0.321	
Tools and sundries	0.015	
Labor	0.104	$0.645
Binder (1½-in.):		
Materials	$0.195	
Fuel	0.011	
Labor, yard	0.030	
Labor, laying	0.025	
Teams hauling	0.025	$0.287
Surface (2-in.):		
Material	$0.666	
Fuel	0.023	
Tools and sundries	0.056	
Labor, yard	0.041	
Labor, laying	0.053	
Labor, general	0.029	
Teams hauling	0.035	$0.903
General expense	$0.057	$0.057
Grand total		$2.180

Contract C varies from the others in having a 1-in. binder and a 1½-in. surface specified. As a matter of fact, however, the asphalt was laid thicker than specified, due to the fact that the men had not been used to laying any light pavement that year. The work was located near the paving plant, also near the source of supply of cement, etc. The weather was good. The cost was naturally low.

CONTRACT C.
(2,404 sq. yds.)

	Per sq. yd.	Total Per sq. yd.
Grading street:		
Sundries	$0.021	
Labor	0.110	
Teams	0.091	$0.222
Concrete base (6-in.):		
Cement, at $0.876 per bbl.	$0.151	
Sand, at $0.71 per cu. yd.	0.039	
Stone	0.205	
Tools and sundries	0.016	
Labor	0.069	$0.480

CONTRACT C (CONTINUED).

(2,404 sq. yds.)

	Per sq. yd.	Total Per sq. yd.
Binder (1-in):		
Materials	$0.152	
Fuel	0.009	
Sundries	0.001	
Labor, yard	0.027	
Labor, laying	0.020	
Teams hauling	0.005	$0.215
Surface (1½-in.):		
Materials	$0.495	
Fuel	0.019	
Tools and sundries	0.042	
Labor, yard	0.043	
Labor, laying	0.062	
Labor, general	0.022	
Teams hauling	0.007	$0.690
General expense	$0.057	$0.057
Grand total		$1.664

Cost of Asphalt Pavements at Winnipeg.—The following data are given by H. N. Ruttan, City Engineer of Winnipeg, Manitoba, on the cost of laying asphalt with a municipally owned plant. In 1899, the city purchased a second-hand stationary plant for $12,322, and made the following additions:

New 10-ton roller	$ 3,500
New sheds, etc.	733
Tools bought 1899	262
Tools bought 1900	121
Maintenance 1899	568
Maintenance 1900	1,048
	$ 6,232
Second-hand plant	12,322
Total	$18,554

The maintenance items consisted largely in repairs to the second-hand plant necessary to put it in first-class condition. The plant includes 2 asphalt melting tanks, sand drum, cold and hot sand elevators, millstone for grinding limestone, storage tank for hot asphalt, storage bins for ground limestone and hot sand, mixer of 7 cu. ft. capacity, 60-hp. boiler, 30-hp. engine, air compressor and receiver, 5-ton roller, 10-ton roller, and accessories. The force required to operate the mixing plant was as follows:

1 superintendent	$ 8.00
1 engineman	3.00
2 firemen	4.00
2 asphalt melters	4.00
1 asphalt dipper and mixer	2.00
1 measurer of sand and limestone	2.00
2 sand and limestone shovelers	2.00
1 record keeper	4.00
1 man for odd jobs	2.00
Total labor for 9 hrs.	$31.00

I have assumed the above rates of wages, but it is stated that the

total cost of operating was $40 a day, which doubtless includes the cost of 1½ or 2 tons of coal. It is stated that in 1900 the prices of materials and labor were as follows, on cars:

Asphalt, per short ton	$36.00
Portland cement, per bbl.	3.65
Sand, per cu. yd.	1.35
Broken stone, per cu. yd.	1.10

Common labor is said to have been 17½ to 20 cts. per hr.; teams, 40 cts. per hr.

Asphalt pavement, consisting of 1½-in. binder and 2-in. wearing surface, laid on a 4½-in. Portland cement concrete foundation, cost $2.04 per sq. yd. for materials and labor. The concrete foundation cost $0.74 per sq. yd., leaving $1.30 per sq. yd. for the asphalt and the grading. It will be noticed that interest and depreciation are not included.

The plant has a capacity of 1,000 sq. yds. of 2-in. wearing surface, or 1,500 sq. yds. of 1½-in. binder, which is equivalent to saying that it has a capacity of about 60 cu. yds. of asphalt, measured in the street, per day of 9 hrs.

In 1899 the city laid 45,800 sq. yds.; in 1900, it laid 22,000 sq. yds. If we assume 30,000 sq. yds. as a fair average for a term of 10 years, the plant would pay for itself by charging 6 cts. per sq. yd. for plant, and it would be occupied about 60 days of actual work per year. But we should not lose sight of the fact that the services of an expert to run the plant could not be secured on the basis of a few dollars a day for only a small fraction of the year. Indeed the cost of an expert's annual salary alone might very easily run up the cost an amount equivalent to 10 cts. per sq. yd.

Since the above was written I have secured the following additional data for the year 1903. The plant has been enlarged and its estimated value is now $21,082. The charges against this plant for the year 1903 were as follows:

Maintenance and repairs	$2,297
¼ cost of new tools	236
4% interest on $21,082	843
5% depreciation on $21,082	1,054
Lost taxes	100
Total plant charge, 65,381 sq. yds. at 6.93 cts.	$4,530

In 1903 there were laid 65,381 sq. yds., so that the charge for plant was 6.93 cts. per sq. yd. The soil is clay and upon it is spread 3 ins. of sand and gravel before laying the concrete base. The cost of the pavement in 1903, including grading, was as follows:

	Per sq. yd.
Grading, including cross-drains	$0.15
Sand, 3-in. foundation	0.15
Concrete, 4½ ins. thick	0.65
Binder coat	0.28
Surface coat	0.60
Plant charges	0.07
Total	$1.90

The prices paid for materials, f. o. b. Winnipeg, in 1903, were as follows:

Portland cement, per bbl	$ 2.96
Broken stone, per cu. yd.	1.30
Sand and gravel, per cu. yd.	1.00
Crushed granite, per cu. yd.	5.00
Asphalt, per ton	26.37
Maltha, per imp. gal.	0.12
Common labor, per 9-hr. day	$1.80 to 2.25
Skilled labor, per 9-hr. day	2.70
Foremen	$3.00 to 4.00
Superintending chemist (for 5 or 6 mos.)	8.00

Mr. Ruttan informs me that a 2-in. surface coat (Bermudez) costs as follows at the mixer:

	Per sq. yd.
0.06 cu. yd. (135 lbs.) sand, at $1.35	$0.081
21 lbs. dust, at $2.60 per ton	0.027
3.5 lbs. oil, at 1⅓ cts.	0.048
15 lbs. Bermudez (gross), at 1.93 cts.	0.291
Labor at the mixing plant	0.048
Fuel (wood)	0.018
Total, at the mixer	$0.517

This gives a weight of 117 lbs. per cu. ft.

Cost of Laying Asphalt Pavement.—The following shows the labor cost of laying asphalt on a concrete base at Rochester, N. Y. A binder coat, ½-in. thick, was first laid; then a wearing, or surface coat 1½ ins. thick; making a total of 2 ins. The gang consisted of 16 men, working part of the time on the "binder" and part of the time on the "surface coat," as follows:

Binder gang.	Surfacing gang.
4 barrow loaders.	4 shovelers.
4 barrow wheelers.	5 rakers.
2 rakers.	2 tampers.
2 tampers.	2 smoothers.
1 wagon unloader.	1 cement spreader.
1 tar melter.	1 iron heater.
1 iron heater.	1 foreman.
1 foreman.	16 men.
16 men.	

The binder gang averaged 2,250 sq. yds. (= 31 cu. yds.) in 10 hrs. of ½-in. binder coat laid, although they frequently laid 390 sq. yds. in an hour. The surfacing gang averaged 1,800 sq. yds. (= 75 cu. yds.) of 1½-in. surface coat in 10 hrs., although they frequently laid 260 sq. yds. in an hour. There were two asphalt steam rollers constantly at work, with this gang of 16 men. In laying several thousand yards of this 2-in. asphalt pavement, I found the average labor cost to be as follows, the gang laying 1,000 sq. yds. per day:

15 laborers, at $1.50	$22.50
1 foreman, at $4.00	4.00
2 roller engineers, at $3.00	6.00
Fuel for rollers	2.50
Total for 1,000 sq. yds. of 2-in. asphalt, at 3½ cts.	$35.00

This is equivalent to 3½ cts. per sq. yd. for laying and rolling, or 63 cts. per cu. yd.

The haul from the mixer to the street was 3 miles, and each

team made 4 trips daily, averaging only 1½ cu. yds. of loose material per load. It took 2¾ cu. yds. of loose material in the wagons to make 2 cu. yds. packed by the roller, or a shrinkage of 25%. The wagons were slat-bottom wagons, and it took about 8 mins. to dump a wagon, but fully as much more time was lost waiting for other wagons, turning around, etc., which time was made up by trotting back. There were 17 teams kept busy, at $3 per day each, making the cost 5 cts. per sq. yd. for hauling the asphalt 3 miles.

Cost of Asphalt Pavement, New York.*—In the following tabulation is given the labor cost to the contractor of laying 8,900 sq. yds. of asphalt pavement on Broadway, from 110th street to 119th street, west side, New York. The work was done in November, 1904. The wages paid were on the basis of an 8-hr. day. The concrete foundation for the asphalt pavement was 5 ins. thick and was composed of 1 part of cement, 3 parts of sand and 6 parts of broken stone. In preparing the concrete for the foundation a Foote mixer was used. The inefficiency of the concrete workmen is well shown by the following cost:

	Per sq. yd.
Concrete:	
0.008 day foreman, at $3.75	$0.03
0.162 day laborers, at $1.50	.243
0.008 day teams, at $5.00	.04
0.008 day steam engine, at $3.50	.028
Total concrete labor, per sq. yd.	$0.34
Binder:	
0.0004 day foreman, at $4.00	$0.0016
0.0008 day engineman, at $4.00	.0032
0.0063 day labor, spreading, at $1.75	.011
0.0009 day labor, ramming, at $2.25	.002
Total binder, per sq. yd.	$0.018
Wearing surface:	
0.0005 day foreman, at $4.00	$0.002
0.0040 day laborers, at $1.75	.007
0.0010 day engineman, at $4.00	.004
0.0070 day labor, spreading, at $1.75	.012
0.0008 day labor, raking, at $2.50	.002
0.0009 day labor, ramming, at $2.25	.002
0.0016 day labor, ironing, at $2.50	.004
Total surface coat, per sq. yd.	$0.033

The binder was 1 in. thick, and the surface coat was 1½ ins. thick, making a total of 2½ ins. of asphalt. It will be seen that the laying cost of laying this asphalt was 1.8 cts + 3.3 cts. = 4.1 cts. per sq. yd.

Cost of Patching Asphalt, Indianapolis, Ind.†—Mr. S. R. Murray gives the data upon which the following is based.

Work on the municipal repair plant of Indianapolis, Ind., was begun on April 16, 1908, and on June 16, 1908, the first asphalt mixture was turned out. The plant was made by Werthington & Berner and has a capacity of 1,200 sq. yds. of 2-in. asphalt. The total cost of the plant, one 5-ton steam asphalt roller, four dump wagons, fire wagons, office building, roller, stone dust and tool sheds and all tools

**Engineering-Contracting*, May 16, 1906.

†*Engineering-Contracting*, Feb. 27, 1909.

necessary to carry on the work, amounted to $20,557.68. This also includes the cost of grading off the yard for plant, putting brick driveway under mixer and cement floor around cold sand elevator. The plant itself cost $15,525.

Between June 16 and Dec. 31, the following was the plant output:

	Boxes.
Surface mixture	16,691
Binder	1,730
Total	18,421

A "box" was 9 cu. ft. of mixed material measured at the plant. Hence the total output was 165,789 cu. ft. of surface and binder, measured before rolling. With this there were laid:

	Sq. yds.
Surface, or wearing coat	92,472
Binder	11,271

It will be seen that each box (9 cu. ft.) of surface mixture made 5.54 sq. yds. of wearing surface, indicating that the wearing surface measured 2.17 ins. thick before rolling. If it was compressed 33% under the roller, the thickness was reduced to 1.45 ins. If it was compressed 16⅔% (a common assumption) the thickness was reduced to 1.8 ins.

The total cost of 82,908 sq. yds. of wearing surface (without any binder) laid in repairing 50 different streets was $51,900, or $0.625 per sq. yd. for all expenses, including interest, at 5%, on the $20,600 plant for 6½ mos., and depreciation at 5% for 6½ mos.

This $0.625 per sq. yd. is equivalent to $3.46 per box of 9 cu. ft., or $0.39 per cu. ft.

The work was done on the same basis as other city work, 8 hrs. per day, and was performed under the most favorable conditions, as a great many of the repairs were large and close together. Only one day was lost account of rain, and four days lost waiting for material.

Only seven hours were lost on account of the plant not being ready when called upon; two hours on account of the breaking of a driving pinion and five hours for replacing brick work in the furnace under the sand drier. This, it will be noted, is a very small loss of time when it is considered that the plant turned out 18,421 boxes in all.

Maltha California asphalt was used for the most part on the repair work; but on account of the West Michigan St. being under guarantee and specifications calling for this material, Trinidad Pitch Lake asphalt was used in its resurface, which involved 9,500 sq. yds.

Petroleum residuum was used as a flux and the very best of material and workmanship were used throughout.

The cost of materials used in the plant was as follows.

California asphalt, $23 per ton.

Trinidad asphalt, $29 per ton.

Limestone dust, $3 per ton.

Residuum oil, average 5 cts. per gal.

Sand, 90 cts. per cu. yd.

Common labor was paid 20 cts. per hour, skilled asphalt men re-

team made 4 trips dail
terial per load. It took
to make 2 cu. yds. pa
The wagons were slat-
dump a wagon, but ful
other wagons, turning
trotting back. There w
making the cost 5 cts.

Cost of Asphalt Pave
tion is given the labor
of asphalt pavement on
west side, New York.
wages paid were on the
tion for the asphalt pa
of 1 part of cement, 3
In preparing the concre
The inefficiency of the
lowing cost:

Concrete:
0.008 day forem
0.162 day labore
0.008 day teams,
0.008 day steam

Total concret
Binder:
0.0004 day forem
0.0008 day engine
0.0063 day labor,
0.0009 day labor,

Total binder,
Wearing surface
0.0005 day foreman
0.0040 day laborers
0.0010 day enginem
0.0070 day labor, s
0.0008 day labor, ra
0.0009 day labor, ra
0.0016 day labor, ir

Total surface co

The binder was 1 in. thi
thick, making a total of 2½
laying cost of laying this asp
sq. yd.

Cost of Patching Asphalt, In
gives the data upon which the
Work on the municipal repai
begun on April 16, 1908, and on Ju
ture was turned out. The plant wa
and has a capacity of 1,200 sq. yds.
of the plant, one 5-ton steam asphalt
wagons, office building, roller, stone dus

*Engineering-Contracting, May 16, 190
†Engineering-Contracting, Feb. 27, 1909.

ceived $2.50 per 8-hr. day, teams were paid for at rate of $3.50 per day, roller engineers received $2.50 per day, and foremen received $4 per day.

High Cost of Patching Asphalt, New Orleans.*—The total amount of asphalt pavement in New Orleans, maintenance of which by its contractors had expired prior to Jan. 1, 1908, was 549,749 sq. yds. Of this amount 398,536 sq. yds. is to be maintained by the city, and 151,213 sq. yds. by the New Orleans Ry. & Light Co.

In order to care for this pavement the city decided to erect a repair plant, and accordingly in 1904 asked bids for furnishing and erecting plant. The specifications under which bids were asked gave the fullest latitude to bidders in designing the arrangement of the plant and in selecting the machinery, apparatus, fixtures, etc. It was required, however, that the plant be operated with coal as a

Fig. 12. Asphalt Plant.

... of turning out each 10-hr. working day ... yds. of binder when laid 1½ ins. thick after ... or 1,000 sq. yds. of pitch asphalt wearing ... after compression. The Warren Bros. ... Cambridge, Mass., was the only bidder, and ... The plant was accepted by ... A report on the operation of the plant for ... has just been made by Mr. W. J. ... from this report has been taken the ...

... in a lot of ground 175 ft. x 260 ft. ... employed for garbage disposal pur... erected by the Warren Bros. ... about 1,300 sq. ft. of ground and con... concrete foundation, brick walls ... expanded metal and cinder concrete ...

[illegible] the [illegible] and the asphalt melting tanks each have a [illegible] and foundation of concrete, independent of the foundation of the building. The [illegible] or stone bin, and the mixer, together with their auxiliary apparatus, are carried on a conical-shaped [illegible] tower erected just within the building and [illegible] on concrete foundations independent of building [illegible].

The cost of the plant and the appurtenant structures was as follows:

Demolition of old garbage plant buildings	$ 475
Asphalt Plant—Warren Bros. Asphalt Paving Co.'s contract, $16,[illegible]; city alterations and additions, $2,736.14	19,[illegible]
Yard fences and gates	[illegible]
Switch tracks	[illegible]
Yard pavements and drains	[illegible]
[illegible] tank and filter	[illegible]
[illegible] pipes and outlets	[illegible]
[illegible] and platform	[illegible]
Asphalt shed	[illegible]
Blacksmith shop and equipment	[illegible]
[illegible], rolling pen and wagon shed	[illegible]
[illegible] crusher and storage bin	[illegible]
[illegible] material bins	[illegible]
[illegible] and store room building	[illegible]
[illegible] bins and roads	[illegible]
[illegible]	[illegible]
[illegible] cleaning of premises	[illegible]
Total	$48,[illegible]

[illegible]—No allowance is made for value of the land.

[illegible] stock consist of 17 mules and 2 horses; the mules are [illegible] and carts and the horses in buggies.

[illegible] stock consists of 14 Watson (2-cu. yd.) asphalt dump [illegible] (2-cu. yd.) single-mule dump carts; 2 Tennessee 4-wheel [illegible] capacity of 4,000 lbs. each; 1 (4-wheel) flood dray, [illegible] capacity of 4 tons; and 1 single-horse storm buggy. [illegible] cart is equipped with a canvas (tarpaulin) cover.

[illegible] tools of various kinds necessary to operate the [illegible] the Warren Bros. Asphalt Paving Co., the plant [illegible] the following: 1 Fairbanks platform scales [illegible] materials; 1 (4-wheel) 3 ft. [illegible] in. by [illegible] [illegible] trucks; 22 iron frame and [illegible] wheel- [illegible] shovels; 12 long-handle shovels; [illegible] [illegible], enamel signs; and a [illegible]

[illegible]

[illegible]

ceived $2.50 per 8-hr. day, teams were paid for at rate of $3.50 per day, roller engineers received $3.50 per day, and foremen received $4 per day.

High Cost of Patching Asphalt, New Orleans.*—The total amount of asphalt pavement in New Orleans, maintenance of which by its constructors had expired prior to Jan. 1, 1908, was 549,749 sq. yds. Of this amount 398,536 sq. yds. is to be maintained by the city, and 151,213 sq. yds. by the New Orleans Ry. & Light Co.

In order to care for this pavement the city decided to erect a plant, and accordingly in 1904 asked bids for furnishing and erecting a repair plant. The specifications under which bids were asked gave the fullest latitude to bidders in designing the arrangement of the plant and in selecting the machinery, apparatus, fixtures, etc. It was required, however, that the plant be operated with coal as a

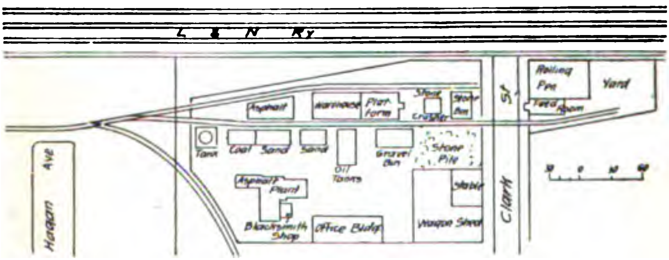


Fig. 12. Asphalt Plant.

fuel, and that it be capable of turning out each 10-hr. working day not less than 1,000 sq. yds. of binder when laid 1½ ins. thick after compression on the street, or 1,000 sq. yds. of pitch asphalt wearing surface when laid 2 ins. thick after compression. The Warren Bros. Asphalt Paving Co., of Cambridge, Mass., was the only bidder, and on Dec. 5, 1905, its bid was accepted. The plant was accepted by the city on Aug. 21, 1906. A report on the operation of the plant for the year ending Aug. 31, 1907, has just been made by Mr. W. J. Hardee, City Engineer, and from this report has been taken the matter in this article.

The plant, Fig. 12, was erected in a lot of ground 175 ft. x 260 ft., owned by the city and formerly employed for garbage disposal purposes. The plant, furnished and erected by the Warren Bros. Asphalt Paving Co., covers about 1,500 sq. ft. of ground and consists of a building formed of concrete foundation, brick walls and floors and roof of steel beams, expanded metal and cinder concrete. The boiler and engine section is 1 story high; the dryer section and the asphalt melting tanks section are each 2 stories high, and the central or tower section, containing the sand bin, the mineral dust bin, and the mixer, is 3 stories, or 32 ft. high. The boiler and

*Engineering-Contracting, Feb. 5, 1908.

engine, the dryer, and the asphalt melting tanks each have a substantial foundation of concrete, independent of the foundation of the buildings. The hot sand, or stone bin, and the mixer, together with their auxiliary apparatus, are carried on a conical-shaped steel frame, 4-legged tower erected just within the building and resting on pier concrete foundations independent of building foundations.

The cost of the plant and the appurtenant structures was as follows:

Demolition of old garbage plant buildings	$ 475
Asphalt plant—Warren Bros. Asphalt Paving Co.'s contract, $16,862.50; city alterations and additions, $2,736.50	19,599
Yard fences and gates	859
Switch tracks	1,189
Yard pavements and drains	6,721
Tower tank and filter	1,330
Water pipes and outlets	1,015
Warehouse and platform	1,471
Asphalt shed	289
Blacksmith shop and equipment	222
Stable, rolling pen and wagon shed	5,311
Stone crusher and storage bin	1,966
Yard material bins	332
Office and store room building	5,509
Landing bins and roads	1,432
Lighting	352
General cleaning of premises	298
Total	$48,365

Note.—No allowance is made for value of the land.

The live stock consist of 17 mules and 3 horses; the mules are used in wagons and carts and the horses in buggies.

The rolling stock consists of 10 Watson (2-cu. yd.) asphalt dump wagons; 8 (1-cu. yd.) single-mule dump carts; 2 Tennessee 4-wheel wagons with capacity of 4,000 lbs. each; 1 (4-wheel) float dray, 5-in. tires, with capacity of 6 tons; and 1 single-horse storm buggy. Each wagon and cart is equipped with a canvas (tarpaulin) cover.

In addition to 134 tools of various kinds necessary to operate the plant furnished by the Warren Bros. Asphalt Paving Co., the plant is equipped with the following: 1 Fairbanks platform scales mounted on rollers for weighing materials; 1 (4-wheel) 3 ft. 10 in. by 2 ft. 10 in. Fairbanks wagon hand truck; 12 iron frame and bed wheelbarrows; 6 short-handle shovels; 12 long-handle shovels; 10 axes; 6 picks; 8 crowbars; 8 sledgehammers, assorted sizes; and a number of small tools of various kinds.

The street tools consist of the following: 2 large-size tool boxes; 18 wooden street barriers; 1 Universal 8-ton steam asphalt roller; 1 Universal 3½-ton steam asphalt roller; 1 1,000-lb. iron hand asphalt roller; 1 (4-wheel) fire wagon for heating, tamping and smoothing irons; 1 (2-wheel) 100-gal. mixing kettle; 18 asphalt tamping irons; 15 asphalt smoothing irons; 66 asphalt axes; 107 picks; 18 mattocks; 102 long-handle shovels; 40 short-handle shovels; 24 iron frame and bed wheelbarrows; 6 axes; 200 lin. ft. of 1-in. diameter wire wrapped rubber hose; 6 sledgehammers; 8

chisels of various sizes; 10 crowbars; and a number of small tools of various kinds.

The testing laboratory, operated in connection with the plant, is equipped with cement testing apparatus, oil tester, brick tester, etc.

The cost of this equipment may be summarized as follows:

Live stock, harness and stable equipment	$ 6,197
Rolling stock and equipment	3,180
Plant tools	837
Street tools	5,492
Office furniture	447
Laboratory equipment	1,490
Total	$17,644

Soon after the plant was placed in operation the city ordered it to do a considerable amount of work not originally contemplated. This included the repairing of streets other than those paved with asphalt, and accordingly the following additional equipment was purchased:

Pioneer 7-ton steam road roller	$1,113
Champion steel road grading machine	150
Austin 700-gal. capacity road sprinkler	396
Rolling stock	1,027
Railroad plows with extra points	39
Wheel scrapers	140
Harness	139
Live stock	1,700
Total	$4,704

For the plow and grading machine mules 17½ hands high and weighing about 1,600 lbs. were secured.

Summarizing, the total cost of the plant and equipment is seen to be as follows:

Structures and their equipment	$48,365
Equipment	17,673
Additional equipment	4,704
Total cost	$70,583

The largest day's run made by the asphalt plant was on June 24, 1907, when surfacing (new pavement) the Esplanade-Claiborne Ave. intersection. In 9 hrs. 205 boxes, gross, of "wearing surface" mixture were turned out; 3 Watson wagons hauled this material from the plant to where it was laid, a distance of a little more than 2 miles; and this material completed 1,020 sq. yds. of pavement intended to be 2 ins. in thickness. The cost of the fuel and labor, including wages of plant foreman, employed in preparing the "wearing surface" mixture; the wages of wagon drivers and the care and feed of the teams; and the labor, including foreman, roller men and fuel, in laying this "naptha coat" and "wearing surface" amounted in all to $127.23, or 12.47 cts. per sq. yd.

The repair plant force worked every working day of the year when it did not rain. The asphalt plant worked 141 days and turned out 9,883 boxes, or 88,947 cu. ft. of wearing surface mixture. It was estimated that a 9 cu. ft. box would lay 5 sq. yds. of 2-in. wearing surface, assuming that the loose material compresses 16⅔% under the roller. On this assumption 49,415 sq. yds. of 2-in.

wearing surface would have been laid. As a matter of fact, only 44,300 sq. yds. were laid, due to using a greater thickness than 2 ins. This greater thickness was necessitated because no "binder" coat was laid to replace any of the old binder removed from the street. Instead of a binder coat, the concrete was "painted" with a "naphtha coat."

Naphtha binder was not only much cheaper, but Mr. Hardee considers it also much more substantial and durable. Naphtha coat is formed of vaporized gasoline and asphalt mixed in equal proportions; it is put on the concrete foundation, when the same is perfectly dry, by hand, with brushes, just as paint would be applied, and to the least possible thickness; it is practically impervious to moisture and prevents the moisture that is commonly ever present in the concrete foundation of our pavements from attacking, through capillary attraction, the base of the asphalt "wearing surface" and rotting it; additionally, the "naphtha coat" effects a strong union of the concrete foundation and the asphalt "wearing surface" and prevents the latter from being displaced in warm weather, as is so frequently the case in old pavements in which gravel "binder" has been employed. In repairing old pavements, where the combined thickness of the "binder" and "wearing surface" was considerably more than 2 ins., concrete was generally added to the original concrete foundation.

From time to time such laborers, additional assistant foremen and other employes, as were required, were hired by the day. When operations were first commenced nearly all the plant and street employes were negroes, but as fast as white men who could satisfactorily do the work were found, the negroes were displaced; within a few months six negroes only remained and these were engaged at the plant on a class of work for which white men were not well fitted.

Teamsters and some of the laborers were paid at the rate of $1.75 per day; but the large majority were paid at the rate of $2 per 10-hr. day. Pavers, stone workers and brick masons were paid from $2.50 to $4 per 8-hr. day.

The following is a list of the permanent employes:

	Annual wage.
Superintendent	$ 2,500
Secretary	1,800
Stenographer	720
Street foreman	1,500
Assistant street foreman	1,200
Yard foreman	1,500
Engineman	1,500
Fireman	780
Steam roller engineman	1,380
Blacksmith	1,080
Yard clerk	720
Messenger	600
Hostler	720
Night watchman	720
Veterinary	180
Chemist, ½ of $1,800	900
Chemist helper, ½ of $720	360
Total	$18,160

For reasons that are not made at all clear in his report, Mr. W. J. Hardee, City Engineer, deducts the following salaries from the above, and puts them in an account that he designates by the very ambiguous phrase "Special Charges":

Chemist	$ 720
Chemist helper	310
Engineman	1,450
Fireman	725
Total salaries in "Special Charges"	$3,205

Deducting this $3,205 from the annual salaries of $18,160, we have left $14,955, which somehow becomes $15,674 when recorded in the "Annual Employes' Salaries."

Then the account of "Special Charges" contains the following:

Salaries (as above given)	$ 3,205
½ laborer's wages at the plant	8,092
342 tons coal at the plant, at $2.84	972
Supplies at the plant	606
Wood at the plant	76
Gas and laboratory supplies	16
Damaged cement	100
Total "Special Charges"	$13,067

Then under an account designated as "General Charges" is placed the $15,674 of "annual employes' salaries," also "one-half day laborers' wages at the plant"; but, unless the purpose is to confuse the analyst of these costs, there appears to be no sound reason for separating the "plant labor" into two halves, as is thus done.

The following is the statement of "General Charges":

Annual employes' salaries	$15,673.96
One half day laborer's wages at plant	8,092.35
Live stock feed	3,032.76
Electric lighting	331.75
Electricity for crusher	133.35
Water at plant	300.00
Water on street	163.50
Blacksmith's supplies	87.52
Office supplies	436.00
Stable supplies	309.30
Horseshoeing	494.70
Extra teams	1,629.10
Car fare and incidental expenses	570.90
Lost and worn-out tools	265.80
Lost live stock	270.00
Total "General Charges"	$31,790.99

The cost of 300 cu. yds. of concrete and 35,905 sq. yds. of "wearing surface" supposed to be 2 ins. thick, was as follows per sq. yd. of 2-in. asphalt wearing surface:

	Total.	Per sq. yd.
Materials	$15,279	$0.425
Special Charges (pro rated)	6,761	0.189
General Charges (pro rated)	11,090	0.309
Other labor	7,177	0.200
Total, Repairs to Asphalt	$40,307	$1.123

As I shall show presently, there is no valid excuse for prorating the "Special Charges" or the "General Charges" in this manner.

In addition to the above given repairs, 8,400 sq. yds. of new asphalt pavement, on a 6-in. concrete base, were laid, and excavation made for the same, at the following cost:

	Total.	Per sq. yd.
Materials (asphalt and concrete materials)	$12,130	$1.444
Special Charges (pro rated)	6,305	0.750
General Charges (pro rated)	10,342	1.231
Other labor	8,812	1.050
Total, New Pavement	$37,589	$4.475

This is "saving the contractor's profits" with a vengeance. A cost of $4.48 per sq. yd. of 2-in. asphalt on a 6-in concrete base, is approximately three times what it would cost any capable contractor. Bear in mind, also, that the $4.48 does not include any allowance for plant interest and depreciation.

Finally, in addition to the asphalt repairs and the new asphalt pavement above given, there was a considerable amount of "Miscellaneous Improvements," such as curb setting, repairing with crushed stone, grading, filling, and the like, the total cost of which was:

Materials	$13,854
General Charges (pro rated)	10,364
Other labor	7,129
Total, Miscellaneous Improvements	$31,347

Analysis of the above costs discloses how the "special charges" and the "general charges" were prorated, namely, according to the cost of the materials used on the three classes of work, i. e., on (1) repairs, (2) new pavement, and (3) miscellaneous. A more absurd distribution could not be imagined, for here is an expensive ($70,000) asphalt plant, with 34% of its "general charges" prorated to curb setting, grading, etc.! Were this not done, the costs of the asphalt repairing and new pavement would show up even higher than they do in the above tabulations.

I have arranged the cost of materials and supplies used during the year, under five heads, as follows:

Asphalt Materials and Supplies:

465.99	tons asphalt, at $18.50	$ 8,561
125,527	lbs. fluxing oil, at 7½ cts.	940
6,753	gals. naphtha, at 15 cts.	1,019
3,900	cu. yds. sand, at $1.27	4,953
321	tons mineral dust, at $5.50	1,764
389	tons coal, at $2.84	1,105
90	cords wood	563
	Total asphalt materials	$18,905

Concrete Materials:

1,936	bbls. cement, at $2.04	$ 3,944
700	cu. yds. sand, at $1.27	889
564	cu. yds. gravel, at $2.27	1,272
696	cu. yds. brickbats (for crushing), at $1.48	1,032
	Total concrete materials	$ 7,137

Miscellaneous Materials:	
3,178 cu. yds. clay gravel, at $1.50	$ 4,786
3,618 cu. yds. lake shells, at $1.46	5,304
3,200 new granite blocks, at 7 cts.	227
4,600 old granite blocks, at 4 cts.	184
9,000 new building brick	98
8,500 old building brick	25
32,924 lbs. cast iron	1,289
3,026 lin. ft. drain pipe	979
Total	$12,892
Office Supplies:	
Laboratory	$ 24
Office	436
Engineer	606
Total supplies	$ 1,066
Stable:	
122,172 lbs. oats, at 1½ cts.	$ 1,820
6,600 lbs. bran, at 1 ct.	66
39¾ tons hay, at $24.72	983
Stable supplies $309, blacksmith $87	396
Total stable	$ 3,265
Grand total	$43,265

These prices are all for materials delivered at the plant.

The foregoing distribution, under the five heads, may be slightly in error. The sand, for example, is given as 4,600 cu. yds., without statement as to its use. About 1,400 cu. yds. of new concrete base were laid, which would require about 700 cu. yds. of sand, and I have, therefore, distributed it in that manner, although there was a certain small, but unstated, amount of concrete laid on old concrete base to bring it up to grade.

This distribution of the cost of materials shows conclusively the absurdity of prorating the "General Charges" and "Special Charges" according to the cost of materials. A glance at the items under "Miscellaneous Materials" proves that no appreciable part of the cost of operating a $70,000 asphalt plant should be properly prorated to "Miscellaneous Improvements," as was done. It is true that a rock crusher (which crushed only 1,143 cu. yds. of stone and brickbats during the year) and a road machine, and a few tools (worth about $2,000, exclusive of mules) were used on the "Miscellaneous Improvements"; but so insignificant was the plant necessary for that work that it is manifestly wrong to prorate any asphalt plant charges or any asphalt plant operating expense to these "Miscellaneous Improvements." I have been at some pains to point out these details, for it is a very common practice for managers of municipally operated plants to conceal the true costs of operation by prorating charges in this fashion. The following is my own analysis of the year's operating expense, which errs, if at all, on the side of liberality toward the managers of this municipal plant. I shall not include the cost of the grading nor of the concrete for the new pavement laid, but confine the summary only to the cost of asphalt repairs, giving total costs, and cost per "box" (9 cu. ft.) of wearing surface, there being 9,883 boxes (88,947 cu. ft.), equivalent to 49,415 sq. yds. 2 ins. thick after rolling:

	Total.	Per box. (9 cu. ft.)
Salaried employes	$18,160	$1.838
Laborers' wages at plant	16,184	1.637
Feeding Stock, Etc.:		
Feed for regular teams	$ 3,033	
Blacksmith supplies	88	
Stable supplies	309	
Horse shoeing	495	
Lost live stock	270	
Extra teams hired	1,629	
Total, feeding stock, etc.	$ 5,824	$0.589
Street Labor, Teamsters, Etc.		
On 35,900 sq. yds. repairs	$ 7,177	
On 8,400 sq. yds. new 2-in. surface (estimated)	1,780	
Total street labor, teamsters, etc.	$ 8,957	$0.907
Office Expense, Etc.:		
Engineers' supplies	$ 606	
Office supplies	436	
Laboratory supplies	24	
Total office expense, etc.	$ 1,064	$0.107
Asphalt Materials and Supplies:		
465.99 tons asphalt, at $18.50	$ 8,561	
125,527 lbs. fluxing oil, at 7½ cts.	940	
6,753 gals. naphtha, at 15 cts.	1,019	
3,900 cu. yds. sand, at $1.27	4,953	
321 tons mineral dust, at $5.50	1,764	
389 tons coal, at $2.84	1,105	
90 cords wood	563	
Total asphalt materials and supplies	$18,905	$1.914
Miscellaneous Plant Expense:		
Electric lighting	$ 332	
Water	300	
Lost tools, etc.	266	
Total miscellaneous plant expense	$ 898	$0.091
Plant Charges:		
Interest, 5% of $65,000	$ 3,250	
Depreciation, etc., 10% of $65,000	6,500	
Total plant charges	$ 9,750	$0.987
Grand total	$79,724	$8.070

Note.—I have made no allowance for "ground rental."

Upon Mr. Hardee's assumption that a "box" of wearing coat will lay 5 sq. yds. of 2-in. wearing coat, we have simply to divide all the above items of "cost per box" by 5, to arrive at the cost per sq. yd., which summed up is as follows:

	Per sq. yd.
Salaried employes	$0.368
Laborers' wages at plant	0.327
Feeding stock, etc.	0.118
Street labor, teamsters, etc.	0.181
Office expenses, etc.	0.021
Asphalt materials and supplies	0.383
Miscellaneous plant expense	0.018
Plant charges	0.198
Total	$1.614

The item of plant charges (interest, depreciation and repairs) does not appear in the report of the city engineer, although such an item should always appear, nor is there any allowance for interest on the ground occupied, although it certainly had value. I have assumed the conventional 5% interest and 10% depreciation and repairs on $65.000 plant (omitting about $5,000 of plant used on "Miscellaneous Improvements"). It should be noted that the first cost of this plant is unusually high.

A small part of the item of "Feeding Stock, Etc.," should unquestionably be charged to "Miscellaneous Improvements" and to hauling materials for concrete, but I am unable to segregate the amount, which is inconsiderable anyway.

The item of "Street Labor, Teamsters, Etc.," is exact for the 35,900 sq. yds. of repairs, but the report gave no details that would enable one to arrive at the corresponding cost for the 8,400 sq. yds. of asphalt laid on the new concrete base, so I have prorated it at the same cost as for the 35,900 sq. yds. of repairs, namely at 20 cts. per sq. yd. This cannot be far wrong, and, in any event, the new pavement was less than 20% of the total wearing coat.

We have in this work the highest cost of 2-in. asphalt wearing coat of which I have any knowledge. It even exceeds the cost of Brooklyn municipal work. It forms, indeed, an object lesson of the gigantic folly of doing public work with a municipal plant instead of by contract.

Note especially the fact that my analysis of the true cost of this repair work shows $1.61 per sq. yd., as contrasted with the $1.12 (which, even at that, was an enormously high cost). By improper prorating of "general and special expenses" and by entire omission of any plant interest and depreciation charges, ground rental, etc., it is an easy matter always to give an appearance of lower unit costs than actually exist.

In *Engineering-Contracting,* April 7, 1909, is given an abstract of Mr. W. J. Hardee's report for the year 1908, relating to this same plant. The following is a brief summary:

Repairs of asphalt pavements	$ 27,545.59
New asphalt pavements	14,409.33
Other kinds of new pavements	23,445.84
Miscellaneous improvements	74,398.91
Total	$139,799.67

The repair work consisted of the construction of 2,640 sq. yds. of naphtha coat and 24,081 sq. yds. of asphalt wearing surface, the cost per square yard of wearing surface being as follows:

	Total.	Per sq. yd.
Materials	$ 8,831	$0.367
Labor	6,778	0.281
Proportion special charges	3,153	0.131
Proportion general charges	8,784	0.364
Total	$27,546	$1.143

It will be noted that the same misleading method of prorating "special and general charges" was used, and that the unit cost of these repairs exceeded the cost of work done the previous year.

The new asphalt pavement work consisted in the construction of 7,550 sq. yds. of pavement, the work including 14,580 cu. ft. of concrete, 7,500 sq. yds. naphtha coat and 7,500 sq. yds. 2-in. wearing surface. The gross cost of this was $14,409 or about $1.90 per sq. yd.

The other new pavement work consisted in the construction of vitrified brick and gravel roadways, the total cost of the work being $23,445.84. The largest item of work was for miscellaneous improvements, these consisting of graveling roads, constructing oyster shell pavement, grading, etc. The total cost of these miscellaneous improvements was $74,398. The output of the plant was 86,004 cu. ft. (9,778 boxes) wearing surface mixture, which was employed in new pavements and repair of old pavements. The crusher operated in connection with the asphalt plant crushed 7,834 cu. yds. of old stone at an average cost for labor and electricity of 51.4 cts. per cu. yd. The stone was furnished free of charge. The cost per cubic yard in the previous year was 46.66 cts. Including feed, hostler and stable boy's wages, veterinary's salary, shoeing, medicine, etc., it cost an average of 76 cts. per head per day to feed and care for the live stock, as against 64.9 cts. for the year ending Aug. 31, 1907.

In the first annual report the cost of the plant including equipment is given as $70,583. Additions to the plant costing $4,261 were made in the second year, bringing the total investment for plant and equipment up to $74,844. The asphalt cost $19 per ton delivered.

Cost of Patching Asphalt, Marion, Ind.*—Mr. T. E. Petrie gives the following:

The accompanying data relate to repair work in the city of Marion, Ind., throughout the month of September, 1908. This is a very good average of the season's work, after the force was thoroughly organized and all equipment put into service.

A city of the size of Marion could not afford a plant costing upwards of $20,000, which would possibly remain idle eleven months out of the year; so we had to look for a smaller and less expensive repair plant. We have in our city 6.64 miles of asphalt streets, or 123,486 sq. yds. The first street was constructed in 1899 and the last in 1902. While we have some excellent asphalt streets, some are much below the average. We found in past experience that to rely on the asphalt companies to do our repair work, it was necessary that our streets should become quite bad before any company would agree to come in to do our repair work, as the repair yardage was so small that it would not pay them to move their plant to our city, so we could expect them once in two or possibly three years, even though the street was under guarantee.

In the spring of 1908, even though two of our streets were yet under guarantee, our Board of Public Works came to an agreement with the Barber Asphalt Co. that the city should take care of all streets under guarantee and that the Barber Asphalt Co. would relinquish all retainer claims that they held against the city.

*_Engineering-Contracting_, Feb. 10, 1909.

In the meantime three of our streets became quite bad, so we began to look about for some relief, and finally purchased one of Hooke's largest combined asphalt plants and a carload of asphalt. To this plant was added another pan and a 700-lb. hand roller.

The cost of the plant was as follows:

Combined fire wagon and asphalt heater	$465
Freight	42
Extra pan	43
Hand roller	65
Hand cart	10
Total cost of plant	$625

Depreciation on the plant was figured on the basis of 60 days' use for the season, This, at 10 per cent, amounted to $62.50 or $25.72 for the 25 days for which the cost records are given.

We began work July 20, 1908, and finished or rather run out of material, Nov. 28th. While not working quite all the time we laid 4,142 sq. yds. of patch work. Great care was taken about the work and it is almost impossible to detect many places where patches were made. We used the Acme asphalt, which came already fluxed, and three grades of sand, so as to obtain as nearly a standard mix as possible, as well as to make the mixture as dense as possible.

We used Portland cement as a filler, instead of stone dust, which caused the price per sq. yd. to run up somewhat higher than it would have had stone dust been used.

We had two experienced men in the gang and paid them 25 cts. per hour, all other men were paid 20 cts. per hour. A one-horse dump cart was used for hauling material from stock room to plant, also hauling prepared material to street, and cuttings or old asphalt away, usually hauling same on some nearby street as repairing material. The cart man was paid 27½ cts. per hour.

The full repair gang consisting of 8 men, 3 out on the street and 5 at the plant, and 1 horse cart and driver.

Orders were given to work until the pans were cleaned and filled with sand at the end of each day's work, ready for fire the next morning.

Four-foot wood was generally used for firing, costing $5.50 per cord, yet some shorter wood was used, costing $1.75 per cord. The Portland cement cost $1.40 per barrel; sand cost $0.75 at the plant and the asphalt cost $30 per ton f. o. b. Marion.

During the 25 working days in September a total of 1,308 sq. yds. of asphalt pavement of an average depth of 2 ins. was laid, there being 2,742 cu. ft. of asphalt mixture used, costing 41 cts. per cu. ft. laid. The itemized cost was as follows:

	Total.	Per sq. yd.
Labor	$ 483.64	$0.3697
Asphalt (including freight), at $30 ton	340.34	.2602
Sand, at $0.75	70.12	.0536
Cement (instead of dust)	98.17	.0750
Fuel	72.93	.0557
Cartage, 30 tons asphalt	11.22	.0086
Interest, 6%	15.00	.0114
Depreciation, 10%	25.72	.0120
Total	$1,117.14	$0.8538

Last season was an excellent one to do repair work, on account of there being but little rain. The sand was kept as dry as possible, and therefore was covered at night, and at daytime in case of rain. This materially assisted in the progress of the work as well as in the saving of much fuel.

The plant was located at some convenient point, near where considerable patching was to be done and care was taken not to move the plant too frequently, as this expense will cause the price per square yard to rise quite rapidly. We were able to get out eight batches per day, providing everything worked well. It is intended to enlarge the mixing pans before beginning work this season, and by so doing it is hoped to increase the output fully 25 per cent, and by using stone dust instead of Portland cement for filler, to cut the price down to at least $0.75 per sq. yd. or perhaps lower.

There has been nothing allowed for superintendence of the work as either the city engineer or his assistant will have time to see that work is going on as it should. However, last season I gave this work quite considerable attention, measuring all patches made, as I desired to know just what it was costing per square yard.

I do not anticipate that we will have as much repair work in the next two seasons as we had last season.

Cost of Patching Asphalt, Marion, Ind.*—In 1908 the city of Marion, Ind., had 6.64 miles of asphalt streets or a total of 123,486 sq. yds. of that kind of pavement. In that year the city took over the maintenance of all of the asphalt paved streets and purchased one of Hooke's largest combined asphalt plants for the work. To this plant was added another pan and a 700-lb. hand roller. The cost of the plant in 1908 was as follows:

Combined fire wagon and asphalt heater	$465
Freight	42
Extra pan	43
Hand roller	65
Hand cart	10
Total	$625

In 1908 a total of 4,142 sq. yds. of patch work was laid. Further details of that year's work are given in our issue of Feb. 10, 1909.

Before beginning work in 1909 a new bottom was put in the Hooke pan, and it was also enlarged so that a batch of 16 5/6 cu. ft. of loose mixture was turned out for the 1909 work, instead of 14⅔ cu. ft. as in 1908. This should have increased the output as well as decreased the labor cost. Owing, however, to the fact that a different brand of fluxed asphalt was used in 1909, which, for the same amount of mixture, took about 25% more asphalt, the

**Engineering-Contracting,* Dec. 15, 1909.

material expense was increased, and also the labor cost as it took considerably longer to mix a batch.

In the 1909 work stone dust was used as a filler, whereas in 1908 Portland cement was used for this purpose. In this year's work the Portland cement was used as a top covering only.

The working force consisted of the following:

Plant:
- 1 man at 25 cts. per hr.
- 4 men at 20 cts. per hr.

Street:
- 1 man at 25 cts. per hr.
- 2 men at 20 cts. per hr.

A one-horse dump cart was used for hauling material from stock room to plant, also for hauling prepared material to street and cuttings or old asphalt away. The driver was paid 27½ cts. per hr. This was the same gang as in the 1908 work with the exception of one man. The men, however, were not as energetic to push the work, as they were in the previous year and this brought up the labor cost. In addition the patches were smaller in the 1909 work and this also caused the labor cost to increase, as when many small patches were made in succession the gang at the plant would be compelled to hold back waiting on the men on the street to prepare places to receive the material.

The working season in 1909 was 33 days, and in that time the gang placed 1,451.5 sq. yds. of patches of an average depth of 2 ins. This is an average of about 44 sq. yds. of patchwork per day. A total of 2,828.1 cu. ft. of loose mixture was produced in the season of 33 days or an average of 85.5 cu. ft. per day. This would be an average of about five patches per day, there being 16 5/6 cu. ft. to a patch. As 2,828.1 cu. ft. of loose mixture made 1,451.5 sq. yds. of compacted 2-in. patches, there was about 1.95 cu. ft. of loose mixture per square yard of 2-in. compacted asphalt. This is 1.3 cu. ft. of loose mixture compacted down to 1 cu. ft. For fuel cord wood was used, 16.8 cords being used for this purpose. As the season covered 33 days the average amount of wood consumed per day would be about ½ cord. As there was an average of five batches per day there was about 0.1 of a cord of wood used per batch.

The cost of the various materials used in the work in 1909 was as follows:

Asphalt, including freight, per ton	$28.714
Sand at plant, per cu. yd.	0.75
Cement, per bbl	1.40
Stone dust, including freight and draynge, per ton	3.52
Cordwood for fuel, per cord	4.50

Interest on the plant investment was figured at 6% per annum, or $37.38 for the year. Depreciation on the plant was figured at 10% per annum, or $62.50 per year.

The itemized cost of materials in the asphalt surface was as follows:

	Per sq. yd. 2 ins. thick.
27.17 lbs. fluxed asphalt, at 1.43 cts.	$0.388
14.47 lbs. stone dust, at .176 cts.	.025
.069 cu. yds. sand, at 75 cts.	.052
.0033 bbls. cement, at $1.40	.005
Total materials for surface	$0.470
Labor, at 20 and 25 cts.	$0.426
Wood, 16.8 cords, at $4.50	.052
Cartage of asphalt	.005
Interest on plant	.026
Depreciation on plant	.043
Grand total	$1.022

The average cost per cubic foot material and labor was 52½ cts.

A comparison of the 1908 costs and the 1909 costs may be of interest and accordingly we have abstracted the costs from the former year as given in our issue of Feb. 10, 1909. The costs for 1908 are for 25 working days in September, during which 1,308 sq. yds. of asphalt of an average depth of 2 ins. was laid. The costs in the two years were as follows:

	1908. Per sq. yd.	1909. Per sq. yd.
Labor	$0.3697	$0.426
Asphalt	.2602	.388
Sand	.0536	.052
Cement	.0750	.005
Stone dust	.....	.025
Fuel	.0557	.052
Cartage	.0086	.005
Interest	.0114	.026
Depreciation	.0195	.043
Total	$0.8537	$1.022

In the 1908 work the asphalt, including freight, cost $30 per ton, and wood cost $5.59 per cord. With these exceptions the prices for material and labor are the same as in 1909. Portland cement was used for a filler in 1908, whereas stone dust was used in 1909. In the figures for the 1908 work the depreciation was figured for the 25 days in September only on the basis of 60 days' use for the season; while in the 1909 costs the depreciation is for the entire season.

All of the work was done under the direction of T. E. Petrie, city engineer.

High Cost of Patching Asphalt, Brooklyn, N. Y.—In *Engineering-Contracting,* May 27, 1908, a complete description is given of the municipal asphalt plant in Brooklyn, which was placed in operation, June 13, 1907. The plant was constructed by the Warren Asphalt Paving Co. A 60 h.p. Babcock and Wilcox boiler, and a 56 h.p. engine (Erie Engine Works) and a 9 h.p. engine (Sturdevant Blower Works), furnish the power. Without going further

into details of design, the following summary gives the cost of the plant:

Contract price	$22,485.00
Engine and boiler foundations, piles, etc.	509.54
Office and sheds	712.00
Fire ext'ing	150.00
Oil tank	365.00
Extra parts—machinery	411.76
Office furniture and equipment	174.28
Electrical work, wiring, lights, annunciators	58.80
Four asphalt rollers	6,156.00
Twelve asphalt trucks at	4,920.00
Tools and gang equipment	2,000.45
Miscellaneous	337.35
Total	$38,280.18

Fixed Charges.

Interest on payments on above at 5%	$ 897.10
Depreciations on plant at 10% (6½ months) on $37,892.08	2,052.49
Rent of plant grounds, $1,440 per year, 7 mos.	840.00
Total per annum	$ 3,789.59

The plant was in operation 6½ mos., in 1907, beginning June 13, 1907, and there were 134 working days out of 202.

The output of the plant was 6,951 boxes of wearing surface mixture and 1,524 boxes of binder, total 8,475 boxes. Each of these boxes held 9 cu. ft. of the mixed product, as measured at the plant. It was found that, during the hauling in wagons from the plant to the street, the wearing surface mixture consolidates and looses about 3% of its volume, but the binder mixture does not consolidate appreciably.

The average wagon load is 8 boxes, or 72 cu. ft. of mixture, and the average distance from the plant to the point of repairs was 4.14 miles. Observations on 35 loads showed a traveling speed of only 2.15 miles per hr. A team and wagon cost $6 per 8 hr. day. The cost of hauling, as given below, includes all delays at the plant and on the street, as well as the cost of hauling the old asphalt from the street to the dump, but it does not include the cost of hauling any materials to the plant, for all prices of materials include delivery at the plant. The wages for an 8 hr. day were:

Plant foreman	$6.00
Foreman	4.00
Rakers	2.50
Tampers	2.50
Smoothers	2.00
Laborers	2.00
Team (with driver)	6.00

In making a box of wearing coat 0.3 cu. yd. of net measure of sand was used, but allowing for losses in the yard, shrinkage on drying, etc., 0.4 cu. yd. of sand were bought. According to the statement of total weight of stone dust used, there were 84 lbs. per box, but, according to the cost per box, at $3.50 per ton, it would appear that 63 lbs. were used.

No record was kept of the number of square yards repaired, the

"box" (9 cu. ft.) being the unit of record. For purposes of comparison, however. I have assumed that a 9 cu. ft. box of wearing surface would make 5 sq. yds. of wearing surface measuring 2 ins. thick after rolling. If 9 cu. ft. of loose wearing surface shrinks 1/6, or 16⅔%, under the roller, we have 7½ cu. ft. of compacted wearing surface, which will make exactly 5 sq. yds. 2 ins. thick. However, careful measurements on 27 sq. yds., made in 1905 by Mr. John C. Sheridan, Chief Engineer of the Bureau of Highways of Brooklyn, showed the following:

"When the concrete foundation was completed ordinates were taken every few feet from a line stretched from curb to curb. These sections were taken about 2½ ft. apart. After the 1-in. binder was laid, measurements were made from the line over the same points, and after the 2-in. wearing surface was laid, similar measurements were taken at the identical points, the material having previously been measured in the truck. It was found that there was a shrinkage of 21½ per cent from the loose measure in the truck to the measurement compacted in place, and that there was a shrinkage of 33 per cent from the plant measurement to the measurement compacted in place. This was on the wearing surface; the shrinkage in binder was not determined."*

If we were to assume the greater shrinkage indicated by this experiment, instead of the 16⅔% shrinkage from the measurement at the plant, we should get a very much smaller yardage of 2-in. pavement, and a correspondingly higher cost. I prefer, therefore, to give the benefit of the doubt to the managers of the Brooklyn municipal plant, by assuming that a 9 cu. ft. box will make 5 sq. yds. of 2-in. wearing coat.

The following costs per box, are as I have deduced them from the annual report for 1907, and the costs per sq. yd. are based upon the assumption just stated.

COST OF WEARING SURFACE.

	Per box. (9 cu. ft.)	Per sq. yd. (2-in.)
Materials:		
0.4 cu. yd. gross (0.3 cu. yd. net) sand at $0.75..	$0.299	$0.060
63 lbs. stone dust at $3.50 ton	0.110	0.022
13 lbs., or 1.63 gals. flux at 6⅝ cts. per gal	0.121	0.024
91 lbs. asphalt at $24.80 ton	1.127	0.225
Total materials	$1.657	$0.331
Supplies:		
0.037 tons soft coal for plant at $4.00 per ton	$0.148	$0.030
0.0056 tons hard coal for rollers at $5.50	0.031	0.006
Oil and waste	0.030	0.006
0.008 cords wood for street fire wagon at $11.34	0.091	0.018
Miscellaneous supplies	0.030	0.006
Total supplies	$0.330	$0.066

*Engineering-Contracting, May 19, 1909.

COST OF WEARING SURFACE (CONTINUED).

Plant Charges:	Per box. (9 cu. ft.)	Per sq. yd. (2 in.)
Rent	$0.099	$0.020
Dump privileges	0.018	0.004
Interest on plant, 5% per yr.	0.106	0.021
Depreciation, 10% per yr.	0.242	0.048
Repairs to plant	0.091	0.018
Repairs to tools	0.024	0.005
Total plant charges	$0.580	$0.116
Labor:		
Plant labor (including foreman)	$1.438	$0.288
Hauling, 4.14 miles	0.934	0.187
Street labor (including foreman)	2.356	0.471
Superintendent ($1,363 for 6½ mos.)	0.161	0.032
Total labor	$4.889	$0.978
Grand total	$7.456	$1.491

Attention should be called to the fact that this plant is new, and that repair costs are therefore smaller than they will be later on. There is apparently nothing included for chemist's salary, etc. Nevertheless, the cost of $7.45 per "box," or $1.49 per sq. yd. of 2-in. surface, is enormously high. Note particularly the tremendously high cost of each of the labor items, except the superintendent. Here is a cost of almost $1.00 per sq. yd. for labor alone on a 2-in. wearing surface! Compare this with records given elsewhere in this book. Even the outrageously high cost of similar municipal work at New Orleans is outdone by this municipal asphalt repairing in Brooklyn. (See page 402.) However, they are both typical of municipally-operated plants.

The cost of the binder was as follows:

COST OF BINDER.

Materials:	Per box (9 cu. ft.)
0.385 cu. yds. stone at $1.45	$0.558
0.46 gals. flux at 7⅜ cts. per gal	0.034
25.5 lbs. asphalt at $24.80 per ton	0.312
Total materials	$0.904
Supplies (same as for wearing surface)	$0.330
Plant charges (same as for wearing surface)	0.580
Labor (same as for wearing surface)	4.889
Grand total	$6.703

Table XV shows the output and cost by months:

Cost of Bitulithic and Asphalt Pavements and Repairs, Toronto.* Mr. C. H. Rust, City Engineer of Toronto, is authority for the following:

Most of the streets in Toronto are of a uniform width of 66 ft., and the width of the roadway has been fixed as follows: In busi-

*Engineering-Contracting, Nov. 17, 1909.

TABLE XV.

Brooklyn Asphalt Repair Plant—Monthly Costs, Total Product and Monthly Box Cost.

Month.	Plant Labor.	Street Labor.	Truck-ing.	Product. Boxes.	Labor Cost, Per Box.	Per Cent Street.	Per Cent Plant.	Per Cent Truck-ing.
June	$ 1,004.37	$ 803.75	$ 367.25	331	$6.57	37	46	17
July	1,114.00	3,129.00	1,066.00	1,201	4.42	59	21	20
August	2,032.75	3,619.47	1,359.00	1,330	5.27	52	29	19
September ..	2,056.87	2,930.49	963.00	1,415	4.20	49	34	17
October ...	2,556.50	3,655.98	1,506.00	1,909	4.04	47	33	20
November...	1,470.87	2,998.89	1,537.50	1,305	4.60	50	24	26
December...	1,952.98	2,832.75	1,117.50	984	6.00	46	33	19
Total	$12,188.34	$19,970.33	$7,915.25	8,475	*$4.73	*49.6	*30.4	*19.6

*Average.

ness districts, where the traffic is fairly heavy, or where a double line of street car tracks exist, the width between curbs is 42 ft.; on residential streets the rule is to have the streets 24 ft. between curbs, and in a few cases this has been reduced to 18 ft., but the writer is not in favor of this. By reducing the width of these streets to the above dimensions, a considerable saving has been effected to the property owners, and also a very large saving in the general city taxes by reducing the maintenance, street cleaning, watering, etc.

Asphalt pavements have been in use in Toronto for the past 20 years, and have given general satisfaction. The first pavement laid was of Trinidad Pitch Lake, and several streets constructed of this material have been in use 16 or 17 years before the surface required to be renewed. A few years ago California asphalt was introduced and the pavements constructed of it have shown splendid wearing qualities, and may be expected to give as good satisfaction as the earlier pavements. Texas asphalt has only been used in Toronto for the last two years. The analysis, however, shows up as well as that of any other type of asphalt and may be expected to stand the wear and tear of general traffic equally as well as the others.

This class of pavement is easily cleaned, quickly laid and repaired, and at the present prices is the most economical and satisfactory pavement which can be laid.

Formerly two types were used, namely light and heavy, but experience has led to dividing this into three classes, light, medium and heavy. The light calls for 4 ins. of concrete with 2 ins. of asphalt; medium for 5 ins. of concrete, 1 in. binder and 2 ins. surface, the heavy having 6 ins. of concrete, 1 in. binder and 2 ins. of surface. The price at the present time for light asphalt is $1.45 per sq. yd.; medium, $1.75 per sq. yd., and heavy, $2.00 per sq. yd.

In 1907 the city purchased an asphalt plant with a capacity of 1,500 sq. yds. per day of 8 hrs., and since then not only have some streets been constructed, but all the repairs have been made to pavements which are out of guarantee.

The cost of material and wages in paving work are as follows:

Material:

Asphalt, per net ton, f. o. b. Toronto	$21.95
Screened gravel, per cu. yd., delivered on street	1.60
Pit gravel, per cu. yd., delivered on street	1.05
Sand for asphalt, per cu. yd., at plant	.84
Cement, per bbl., carload lots	1.29
Crushed limestone, per ton, on cars	1.28
Limestone rubble, per ton, on cars	1.10
Crushed granite, per ton, on cars	1.60
Limestone dust for asphalt mixture, per ton, in bags of 90 lbs., on cars	5.60
Granite blocks, per 1,000	67.00
Paving blocks (brick), per 1,000	24.50
Paving bricks, per 1,000	18.00

Wages:

Laborers, per day of 9 hrs	$ 2.00
Pavers, per hr	.25 to .27½
Concrete finishers, per hr	.25 to .35
Asphalt rakers, per hr	.25
Carters (single team), per hr	.35
Teamsters (double team), per hr	.55 5-9
Roller engineer, per hr	.25
Foremen, per day	$3.00 to 4.00

The cost of cement curbs and sidewalks at Toronto is not reprinted here, but may be found in *Engineering-Contracting*, Nov. 17, 1909.

Plant Burden.—The charges for the plant during the year 1909 were as follows:

Sinking Fund on Investment:	
Cost of plant, $33,522, at 7% (rate for 20 yrs.)	$ 2,346.54
Rental of site, one-half of $1,000	500.00
Taxes	309.00
Miscellaneous Services:	
Phone	15.50
Railway siding	60.17
Insurance (fire)	842.00
Depreciation—(a) building, (b) machinery, 5% of $33,522	1,676.10
Fuel:	
18,000 batches at this year's average cost, .06 cts. for fuel	1,080.00
Heat and light in winter	40.00
Management:	
¼ of salary of chemist	300.00
Fixed Charges:	
Foreman	1,014.00
Watchman, summer and winter	608.30
Timekeeper	315.00
Engineer	577.50
Roller	255.00
Repairs	500.00
Total	$10,439.11

Note.—At full capacity the plant develops 38,000 batches in the season of 150 days. An estimate of 18,000 batches as safe, which gives a cost of 58 cts. per batch, burden. If binder is used as well as surface, it makes the cost per batch 75 cts. There are 6 sq. yds. of 2-in. surface to the batch, hence the plant burden is nearly 10 cts. per sq. yd. of 2-in. surface coat.

Cost of Repairs.—The following was the cost of resurfacing 8,117 sq. yds. during the month of June, 1909, with a 2-in. surface coat:

Materials:	Per sq. yd.
0.18 batch asphalt mixture, at $2.12	$0.380
0.18 batch plant burden (as above), at $0.58	0.104
0.2 lbs. stone dust, at $0.30 per cwt.	} 0.006
0.17 lbs. asphalt cement, at $1.25	
0.006 cords wood, at $5.11	
Total materials	$0.490
Labor on Street:	
Laying	$0.082
Carting	0.044
Rolling, 0.023 hrs, at $1.40	0.032
Total labor on street	$0.158

Miscellaneous Charges:	
Office expense	$0.005
Engineering, 3%	0.020
Tools, 1%	0.007
Total miscellaneous	$0.032
Grand total	$0.680

Note that the item "Labor" includes only street labor, and that "asphalt mixture" and "plant burden" includes materials and labor at the plant.

Cost of a Light Asphalt Pavement.—A light asphalt pavement, 18 ft. wide and 544 ft. long, was laid on Broadway. It was begun May 27 and completed June 19, 1909. The 2-in. asphalt surface occupied 950 sq. yds. (after deducting the cement gutter area). The cost was as follows:

	Per sq. yd.
Grading	$0.359
Concrete Foundation (4-in.)	0.577
Asphalt Surface:	
0.158 batch asphalt mixture, at $2.70	0.427
Stone dust, asp. cement and wood	0.004
Carting asphalt mixture	0.038
Labor on street	0.017
Rolling, 0.005 hrs., at $1.40	0.007
Total asphalt surface	$0.488
Miscellaneous charges	$0.100
Grand total	$1.524

The labor on the concrete foundation, exclusive of carting the materials, was only 9 cts. per sq. yd.

Note that the $2.70 per batch of "asphalt mixture" includes labor at the plant and plant burden, as well as materials.

Cost of Medium Asphalt Pavement.—An asphalt pavement (1,651 sq. yds.) consisting of a 5-in. concrete base, 1-in. binder, and 2-in. surface was laid on Sackville St., at the following cost:

	Per sq. yd.
Grading:	
Labor	$0.176
Rolling, at $1.40 per hr.	0.027
Total grading	$0.203
Concrete Foundation	$0.666
Asphalt:	
0.095 batch binder, at $1.98	$0.182
0.17 batch asphalt top, at $2.70	0.450
Stone dust, cement and wood	0.005
Carting	0.037
Labor on street	0.043
Rolling, 0.011 hrs., at $1.40	0.015
Total asphalt	$0.732
Miscellaneous	$0.090
Grand total	$1.610

The labor on the concrete cost 8 cts. per sq. yd., exclusive of carting.

Cost of Bitulithic Pavement.—On Alhambra Ave., for a distance

of 304 ft., a bitulithic pavement was laid on 4-in. concrete, 719 sq. yds., at the following cost:

	Per sq. yd.
Grading	$0.252
Concrete Foundation	0.592
Bitulithic Surface:	
Bitulithic materials	$1.150
Carting	0.093
Labor on street	0.050
Rolling	0.015
Total bitulithic	$1.308
Miscellaneous Charges	$0.170
Grand total	$2.322

Cost of Repairs to Asphalt Pavements, Syracuse, N. Y.*—Valuable data on the amount and cost of repairs of asphalt pavements at Syracuse, N. Y., are given in his annual report by City Engineer H. C. Allen. In addition to the data on life and cost, the report presents a plan, which will interest city engineers, for determining when repairs should cease and the pavement be resurfaced. We quote Mr. Allen's report as follows:

The first asphalt pavements in Syracuse, N. Y., were laid in 1889, 20 years ago. Since that time more or less of this kind of pavement has been laid each year, excepting 1891 and 1892, until at present there are about 625,000 sq. yds., outside of the railroad strip and exclusive of asphaltina. In 1902, the Department of Public Works commenced to repair systematically all asphalt pavements out of guarantee and to make a record of the amount of work done and its cost.

Following is a table showing the total number of square yards of asphalt pavement out of guarantee, and the total cost of repairs each year from 1902 to 1908, both inclusive.

Year.	Total Sq. Yds.	Repairs Sq. Yds.	Total Cost.
1902	154,498	1,414	$ 2,656.40
1903	241,125	2,710	4,586.46
1904	381,180	5,617	9,628.37
1905	396,814	9,308	13,275.43
1906	450,427	14,958	19,447.43
1907	457,152	17,574	24,092.24
1908	494,391	17,821	24,028.03
Totals		69,402	$97,714.36

The total amount of asphalt pavement required was 69,402 sq. yds., and the cost $97,714.36, or $1.41 per sq. yd. of patching. Besides this, there has been a large amount of asphaltina pavement repaired. The laying of asphaltina ceased in 1899 and it has always been kept in repair with asphalt.

During the past two or three years it has been observed that the older asphalt pavements, those laid in 1895 and previous thereto, were fast reaching a condition impracticable to repair, and a time when a new surface must be laid. It was also noticeable that the

Engineering-Contracting, Mar. 3, 1909.

greater part of the cost of repairs was upon these old pavements. Because of these observed facts, and the constantly increasing annual charge for repairs, a study and analysis of the records were undertaken with a view to recommending a policy on the part of the Department of Public Works with reference to the maintenance of this class of pavements. According to the provisions of the Charter, the cost of paving streets has been paid by the owners of abutting property and, after the expiration of the guaranty period, the Department of Public Works has made the necessary repairs. The analysis above referred to show that the cost per square yard per year for repairs to asphalt increases in an increasing ratio. This ratio has been estimated from experience with the pavements in this city as follows:

Year of the Pavement Life.	Cost Per Sq. Yd. Per Yr. at $1.41 Per Sq. Yd.	Total Cost to Date Each Yr. Sq. Yd.
6th	$0.003	$0.003
7th	.011	.014
8th	.014	.028
9th	.028	.056
10th	.035	.091
11th	.056	.147
12th	.085	.232
13th	.127	.359
14th	.169	.528

It is apparent from these figures as well as from the contemplation of the increasing actual cost from year to year, that the repairs to asphalt pavements by the Department of Public Works can not go on indefinitely without involving the resurfacing of entire pavements.

The Charter provides that the resurfacing of street pavements shall be done at the expense of the owners of abutting property, and the problem here to be solved is the determination of the time at which the Department of Public Works shall cease making repairs, and leave the pavement to be resurfaced in the manner provided by law. Several suggestions have been made, one that a pavement having once been laid, the city shall keep it in repair for a certain period of years, say, until it is 15 years old; another that a pavement shall be kept in repair by the city until a certain percentage of its area shall have been repaired.

Objection is found to the first proposition in that the lives of pavements vary with their location and the volume of traffic to which they are subjected. Some of the asphalt pavements are found to have had as low as 1 per cent of the total surface repaired and to be still in fair condition at the end of 12 years, while others not so favorably located and sustaining heavy traffic have had more than 50 per cent of the total surface repaired in the same period, and are not capable of further repairs. It is evident that a hard and fast rule that all asphalt pavements must be resurfaced at the end of 15 years of life will not operate in an equitable and consistent manner, for the reason that in some cases the condition of the pavement, due principally to its use, will require resurfacing at an earlier period, and in others the rule will require the destruc-

tion and replacement of a pavement which still has in it the ability to render service for a longer period.

The proposition that the city keep an asphalt pavement in repair until such a time as a certain percentage of its total area has been repaired seems to meet the requirements of the situation in a more practical and equitable manner.

The study of the information contained in the record of repairs shows that after the tenth year of life, the amount of repairs per square yard per year increases at a much more rapid rate than in previous years. The results obtained by taking the mean or average of the quantity of repairs to pavements which have reached the age considered is as follows:

Year.	Amount of Repairs.	Sq. Yds.
11th Year	—Per Sq. Yd., Per Year	.04
12th Year	—Per Sq. Yd., Per Year	.06
13th Year	—Per Sq. Yd., Per Year	.09
14th Year	—Per Sq. Yd., Per Year	.12
Total repairs		0.31
Average from 6th to 10th year inclusive		0.065
Total for 14 years		0.375

It is also to be observed that in the majority of pavements the general condition at the time repairs to the extent of 37½ per cent have been made is such as to render further repairs impracticable, and resurfacing necessary.

Taking the average of all pavements of this kind, it is found that at the end of the 14 years of life the percentage of 37½ per cent of the total area has been repaired, the extremes being such streets as North and South Salina, which reach the limit in 11 years, and others such as Davis and Fitch streets which have not required 5 per cent repairs in 12 or 13 years.

It is therefore recommended that it be the policy of the Department of Public Works to keep up the repairs to asphalt pavements until such time as the total repairs thereon have reached 37½ per cent of the total area; that having made repairs to that extent upon any pavement it be abandoned for further repairs, and reported to the Common Council as a proper object for resurfacing. It should be noted in connection with this discussion and the general one of the participation by the city at large in the cost of pavements, that by paying the cost of repairs until the time the percentage of total surface above commended has been reached, the city at large participates in the cost of the pavement during the period of its life to the extent of about 53 cts. per square yard or about 30 per cent of the total cost of the perishable portion of the pavement.

[For a correct mathematical discussion of problems of this nature, consult Section I of this book.]

If it is thought to be advisable that the general scheme of paving assessment now in force should be changed by Charter amendment, so that the city at large is made to participate in a portion of the original cost of a pavement, it is suggested that it would be an equitable arrangement in making such assessments to consider that

the streets crossed by any proposed pavement are city property fronting the improvement, and to charge the cost of the pavement to this property at the same rate per foot front as other property along the line is called upon to pay.

Cost of Repairs and Life of Asphalt, Washington, D. C.—Capt. H. C. Newcomer gives the following: On July 1, 1903, there were 2,886,786 sq. yds. of sheet asphalt pavements, on 2,425,732 sq. yds. of which the 5 yr. guarantee had expired. The following is the number of sq. yds. of given age above 5 yrs.:

Age, Years.	Sq. Yds.	Age, Years.	Sq. Yds.
5	97,642	19	60,967
6	99,967	20	108,385
7	81,497	21	95,762
8	109,128	22	106,439
9	105,693	23	126,657
10	101,296	24	66,349
11	130,745	25	35,417
12	209,632	26	21,869
13	202,134	27	15,041
14	165,746	28	30,682
15	59,668	29	1,642
16	97,607	30	23,254
17	70,841	31	7,330
18	45,154	..	....
Total			2,277,144

The average age of the above is 14.8 years. The average age of the areas patched during the fiscal year ending July 1, 1903, was 21 years. The patching is done by contract, and is not paid for by the sq. yd., but by the cubic foot of mixed materials measured in the cart, the price being as follows:

	Per cu. ft.
Asphalt surface	$0.49
Asphalt binder	0.25

The standard pavement has a 6-in. concrete base, a 1½-in. binder course and a 1½-in. wearing surface—total 3 ins. of asphalt measured after rolling.

The contract price for a standard asphalt pavement is $1.59 per sq. yd., the pavement having a 6-in. base (1 part Portland cement, 4 parts sand, 5 parts gravel and 5 parts broken stone), on which is laid 2 ins. of binder and 2½ ins. of asphalt surface, both measured before compression.

The cost of repairs during the year of 1903 was 2.8 cts. per sq. yd. for pavement of all ages, being distributed thus:

Age of Pavements, Years.	Cost Repairs Per Sq. Yd.
5 to 10	1.65 cts.
10 to 15	3.37 cts.
15 to 20	3.78 cts.
20 to 25	2.8 cts.

This relates only to patching and does not include any entire renewals of worn out pavements.

Cost of Repairing Asphalt Pavement in Various American Cities.*—The committee appointed by the Municipal Engineers of the City of New York to investigate the cost of repairing asphalt pavement has submitted a report of their work, from which we take the following data. A blank prepared by the committee was sent to 20 of the leading cities in the country which have the largest amount of asphalt pavements, with the request that it be filled out in detail. The object was not only to ascertain the actual cost and method of repairing asphalt pavements, but if possible to determine the cost of repairs according to the age of the pavements. Only eight of the cities replying have kept their records in such shape that this could be obtained and the results are embodied in the accompanying table. The figures in Table XVI are all for the year 1905 except Washington, which is for the year ending June 30, 1905. Although not being able to furnish just what was desired, the following cities gave information regarding their methods:

In Philadelphia there are about 25 miles of asphalt out of guarantee and it is stated they all required resurfacing entire. The prices for resurfacing in patches of 100 sq. yds. or less for 1906 are $1.19 per sq. yd., patches between 100 and 500 sq. yds. $1.17 per sq. yd., for surfaces from 500 to 1,000 sq. yds., $1.11 per sq. yd., for over 1,000 sq. yds. $1.07 per sq. yd. It is said the amount expended per year depended upon the annual appropriation rather than the need of the streets.

In Minneapolis the area repaired last year was wholly in streets under guarantee where the contractor had failed to live up to his agreement. They were made at a cost of $1.65 per sq. yd. The total yardage laid under this agreement was 4,525 sq. yds., but no statement was made as to the total area of the streets as repaired.

In Omaha the repairs are made by a municipal asphalt plant, and while no statement was made of the cost by the age of the pavements, the total of 5.8% of the entire yardage repaired was relaid. This would mean at a cost of 82 cts. per sq. yd., an average of 4¾ cts. over the entire area.

In Kansas City the method of repairs is such that the following quotation is made from a letter of the Engineer:

"We have repaired since 1903, when the first repairing of asphalt pavements out of maintenance was begun, 41 miles of streets, amounting to 88,000 sq. yds., costing $124,277.65. The cost of this work has been $1.50 per square yard until within the last year, when the Economic Asphalt Repair Co. came into the field with their Surface Heater. Since then the price has been cut to 90 cts. per square yard. Previous to this time all repairing work was done by the Barber Asphalt Paving Co., and the method used was to cut out all worn asphalt and replace by new. This latter method was very unsatisfactory, leaving the street in a lumpy condition, and in a short while after this work was done a bad place or hole was

*_Engineering-Contracting_, Sept. 19, 1906.

TABLE XVI.—COSTS OF REPAIRING ASPHALT PAVEMENTS IN VARIOUS CITIES DURING THE YEAR 1905.

Age of pavement.	Brooklyn. Sq. yds.	Brooklyn. Cost per sq. yd.	Buffalo. Sq. yds.	Buffalo. Cost per sq. yd.	Rochester. Sq. yds.	Rochester. Cost per sq. yd.	St. Paul. Sq. yds.	St. Paul. Cost per sq. yd.	Toronto. Sq. yds.	Toronto. Cost per sq. yd.	Washington. Sq. yds.	Washington. Cost per sq. yd.
6 years..	122,491	.001	....	.....	......	.....	5,077	.0016	......	....	63,520	....
7 years..	82,937	.007	7,862	.0110	......	.....	......	.....	......	....	70,184	.003
8 years..	421,274	.030	139,226	.0210	......	.....	......	.....	......	....	40,150	.002
9 years..	189,415	.018	86,458	.0129	27,680	.0253	11,385	.0812	......	....	70,493	.002
10 years..	209,937	.043	241,666	.0028	17,844	.0183	77,115	.0945	10,499	.043	42,397	....
11 years..	44,056	.027	494,765	.0147	11,003	.0150	......	.....	43,871	.110	83,892	.003
12 years..	41,187	.028	438,540	.0276	57,155	.0093	......	.....	5,456	.043	77,462	.010
13 years..	36,706	.040	325,098	.0419	57,558	.0832	......	.....	41,773	.100	81,078	.014
14 years..	27,419	.060	305,449	.0618	23,548	.0550	.....	.....	20,027	.069	96,863	.008
15 years..	5,278	.026	290,862	.0458	72,573	.0530	......	.....	47,276	.044	128,986	.016
16 years..	29,069	.064	216,660	.0590	54,397	.0788	2,096	.0090	32,640	.032	204,585	.023
17 years..	87,442	.102	108,215	.0430	5,134	.0545	9,654	.0900	......	....	89,336	.039
18 years..	20,504	.151	75,379	.0944	36,352	.0400	48,612	.0076	......	....	20,754	.049
19 years..	235	.031	37,117	.1219	17,433	.0571	30,351	.0015	......	....	37,311	.017
20 years..	3,448	.074	39,398	.0376	9,482	.0864	......	.....	......	....	9,199	.012
Repair Prices or Costs	Wearing surface = 67 cts. per cu. ft. Binder = 25 cts. per cu. ft.		1st 6 months = $1.23 per sq. yd. 2d 6 months = $0.75 per sq. yd.		$1.28 per sq. yd.		$1.65 per sq. yd.		$0.89 per sq. yd.		Wearing surface = 49 cts. per cu. ft. Binder = 25 cts. per cu. ft.	

likely to develop alongside the place repaired. It is also very difficult under this method to get a good joint. These repair contracts are for two years—they agreeing to keep the street in condition during the two years of their contract and tax bills being issued for the work done on the street at the middle and end of the period of their contract. This has resulted in the work being in a state of continual repair, tax bills being issued at the end of each year, at the end of the period of the contract the street being in a little better condition than when started."

In New York City, Borough of Manhattan, it is reported, in 1904, 265,000 sq. yds. were maintained at a cost of $201,167.38, or practically an average of 76 cts. per sq. yd.; in 1905, 460,882 sq. yds., at a cost of $161,800.90, or an average of 34 cts. per sq. yd.; in 1906 there will be maintained 760,091 sq. yds., at an estimated cost of $216,235, or 28½ cts. per sq. yd. The figures of Manhattan are very much more than for any other city. This is probably due, it is considered, to the heavy traffic of the Manhattan streets and the fact that many streets have been paved with asphalt where that material does not make an economic pavement.

[I do not concur with this conclusion at all. The City of New York is one of the most extravagant cities in the world, as well as one that has suffered most from "graft."]

Specific Gravity of Bitulithic and Asphalt Pavements.—Mr. J. W. Howard states that the specific gravity of a sample of bitulithic pavement in Baltimore was 2.69, as compared with 2.96, which was the specific gravity of the broken stone used in its construction, the pavement being only 9% less dense than the stone. He states that asphalt pavements have a specific gravity of 1.90 to 2.24, as compared with 2.60 or 2.70, which is the density of the sand and limestone dust used in their construction, indicating that the pavement averages about 20% less dense than the minerals of which it is made.

Cost of Asphalt Cross Walks.—Mr. H. B. R. Craig gives the data upon which the following is based:

In Kingston, Canada, the crossing of macadam streets are made of asphalt, which has been found to have a life of 10 to 20 years. A small plant, costing only $100, is used. It consists of a 40-gal. asphalt boiler, a sand heater (100 sq. ft. of surface), and a mixing board of the same size. The sand heater is a ½-in. sheet iron plate resting on four brick walls 2 ft. high and 1 ft. thick, enclosing an oven. The fuel (wood) is fed through a hole in the wall.

The following is the gang:

	Per day.
3 men heating asphalt and sand and mixing, at $1.50	$ 4.50
1 cart hauling to the street	2.25
2 men laying and finishing the asphalt surface	3.00
Total, 300 sq. ft., at 3.25 cts	$ 9.75
2 men preparing the foundation, at $1.50	3.00
Grand total, 300 sq. ft., at 4.25 cts	$12.75

The following was the cost of 15,000 sq. ft. of asphalt crossings laid in 1905:

	Per sq. ft. Cts.
Materials:	
Stone	0.267
Asphalt, at 1.57 cts. per lb.	3.690
Cement, at $1.70 per bbl.	0.080
Tarred gravel, at 75 cts. per cu. yd.	0.510
Sand, at 90 cts. per cu. yd.	0.630
Fuel (very cheap)	0.110
Hardware	0.015
Total materials	5.302
Labor:	
Boiling asphalt, heating sand, etc.	1.250
Carting	1.088
Laying and finishing surface	0.917
Preparing foundation	1.020
Total labor	4.275
Grand total	9.577

The fuel was old wood and its cost was merely the cost of hauling it.

The method of construction is as follows: The macadam is shaped to the desired cross-section, and a load or two of tarred gravel is spread across the street. The asphalt mixture is laid on this foundation to a thickness of 2 ins. It is well tamped along the edges and rolled with a 2-man roller. The tamper and roller must be oiled to prevent the mixture from adhering. A thin coating of cement is sprinkled over the surface and wetted down, about 1 lb. of cement for every 10 sq. ft.

The surface mixture is made by heating 270 lbs. of Acme asphalt to 300° F. and maintaining that temperature for 2 hrs., constantly stirring. Twenty bushels of medium coarse sand (screened through ⅛-in. screen) are heated to drive off moisture. The asphalt and sand are mixed by hand on a mixing board.

Asphalt walks are similarly constructed on a base of 4 ins. of tarred gravel laid on rammed cinders.

Cost of Mixing Concrete Base By Hand.—The ordinary labor cost of concrete foundations is 0.4 to 0.5 of a 10-hr. day's wages per cubic yard of concrete, although occasionally it may be as low as 0.3 of a day where two mixing gangs are worked side by side under separate foremen, and under an exacting contractor. In such a case, the rivalry between the two mixing gangs where the progress of the work can be seen at a glance, as in laying pavement foundations, will insure a saving of at least 25% in the labor item. The following, taken from my note-books and time-books, indicates the ordinary cost of concrete mixing and laying:

Case I. Laying 6-in. pavement foundation. Stone delivered and dumped upon 2-in. plank laid to receive it. If dumped directly upon the ground it costs half as much again to shovel it up. Sand and stone were dumped along the street, so that the haul in wheelbarrows to mixing board was about 40 ft. Two gangs of men worked

under separate foremen, and each gang averaged 4.5 cu. yds. concrete per hour.

The labor cost was as follows for 45 cu. yds. per gang:

	Per day.	Per cu. yd.
4 men filling barrows with stone and sand ready for the mixers, wages 15 cts. per hr.	$ 6.00	$0.13
10 men, wheeling, mixing and shoveling to place (3 or 4 steps), wages 15 cts. per hr.	15.00	0.33
2 men ramming, wages 15 cts. per hr.	3.00	0.07
1 foreman at 30 cts. per hr. and 1 water boy, 5 cts.	3.50	0.08
Total	$27.50	$0.61

Case II. Sometimes it is desirable to know every minute detail of cost, for which purpose I give the following:

	—Per cu. yd.— Day's labor.	Cost.
3 men loading stones into barrows	.06	$0.09
1 man loading sand into barrows	.02	0.03
2 men ramming	.04	0.06
1 foreman and 1 water boy equivalent to	.035	0.05
9 men: wheeling sand and cement to mix. board	.02	0.03
9 men: wheeling stone to mixing board	.026	0.04
9 men: mixing mortar	.013	0.02
9 men: mixing stone and mortar	.049	0.07
9 men: placing concrete (walking 15 ft.)	.072	0.11
Total	.335	$0.50

In one respect this is not a perfectly fair example (although it represents ordinary practice), for the mortar was only turned over once in mixing instead of three times, and the stone was turned only twice instead of three or four times. Water was used in great abundance, and by its puddling action probably secured a very fair mixture of cement and sand, and in that way secured a better mixture than would be expected from the small amount of labor expended in actual mixing. About 9 cts. more per cu. yd. spent in mixing would have secured a perfect concrete without trusting to the water.

Case III. Two gangs (34 men) working under separate foremen averaged 600 sq. yds., or 100 cu. yds. of concrete per 10-hr. day for a season. This is equivalent to 3 cu. yds. per man per day. The stone and sand were wheeled to the mixing board in barrows, mixed and shoveled to place. Each gang was organized as follows:

	Per day.	Per cu. yd.
4 men loading barrows	$ 6.00	$0.12
9 men mixing and placing	13.50	0.27
2 men tamping	3.00	0.06
1 foreman	2.50	0.05
Total	$25.00	$0.50

These men worked with great rapidity. The above cost of 50 cts. per cu. yd. is about as low as any contractor can reasonably expect to mix and place concrete by hand in pavement work.

Case IV. Two gangs of men, 34 in all, working side by side on

separate mixing boards, averaged 720 sq. yds., or 120 cu. yds., per 10-hr. day. Each gang was organized as follows:

	Per day.	Per cu. yd.
6 men loading and wheeling	$ 9.00	$0.15
8 men mixing and placing	12.00	0.20
2 men tamping	3.00	0.05
1 foreman	3.00	0.05
Total	$27.00	$0.45

Instead of shoveling the concrete from the mixing board into place, the mixers loaded it into barrows and wheeled it to place. The men worked with great rapidity.

Case V. Mr. Alfred F. Harley is authority for the following: In laying concrete foundations for street pavement in New Orleans, a day's work, in running three mixing boards, covering the full width of the street, averaged 900 sq. yds., 6 ins. thick, or 150 cu. yds. with a gang of 40 men. With wages assumed to be 15cts. per hr. the labor cost was:

	Cts. per cu. yd.
6 men wheeling broken stone	6
3 men wheeling sand	3
1 man wheeling cement	1
2 men opening cement	2
7 men dry mixing	7
8 men taking concrete off	8
3 men tamping	3
3 men grading concrete	3
1 man attending run planks	1
3 water boys	1
2 extra men and 1 foreman	4
Total labor cost	39 cts.

Case VI. The following cost of a concrete base for pavements at Toronto has been abstracted from a report (1892) of the City Engineer, Mr. Granville C. Cunningham. The concrete was 1 : 2⅓ : 7½ Portland; 2,430 cu. yds. were laid, the thickness being 6 ins.; at the following cost per cu. yd.:

0.77 bbl. cement, at $2.78	$2.14
0.76 cu. yd. stone, at $1.91	1.45
0.27 cu. yd. sand and gravel, at $0.80	0.22
Labor (15 cts. per hour)	1.03
Total	$4.84

Judging by the low percentage of stone in so lean a mixture as the above, the concrete was not fully 6 ins. thick as assumed by Mr. Cunningham. Note that the labor cost was 1½ to 2 times what it would have been under a good contractor.

It is also noteworthy that Portland cement was used. Until quite recently natural cement has been used almost exclusively in pavement foundations in America. A natural cement concrete is usually made 1 : 2 : 5, the cement being measured loose, so that about 1.15 bbls. of cement are required per cubic yard of concrete. A sufficiently good Portland cement concrete can be made with ¾ bbl. cement per cubic yard; and, if the mixing is well done in a mechanical mixer, it is safe to make concrete for pavement founda-

tions 6 ins. thick using not more than ½ bbl. of Portland cement per cubic yard.

Case VII. Mr. Charles Apple gives the following data on the cost of a 6-in. concrete foundation for a brick pavement at Champaign, Ill. The concrete was 1 : 3 : 3, natural cement, mixed by hand. The material was brought to the steel mixing plate from piles 30 to 60 ft. away.

	Cost per cu. yd.
1.2 bbls. cement, at $0.50	$0.600
0.6 cu. yd. sand and gravel, at $1	0.600
0.6 cu. yd. broken stone, at $1.40	0.840
6 men turning with shovels, at $2	0.080
4 men throwing into place, at $2	0.053
2 men handling cement, at $1.75	0.023
1 man wetting with hose, at $1.75	0.012
2 men tamping, at $1.75	0.023
1 man leveling, at $1.75	0.012
6 men wheeling stone, at $1.75	0.070
4 men wheeling gravel, at $1.75	0.047
1 foreman, at $4	0.027
Total per cu. yd.	$2.387

The cost of mixing and placing this concrete was only 35 cts. per cu. yd., a gang of 26 men and 1 foreman placing 150 cu. yds., or 900 sq. yds., per day. I do not believe these figures of Mr. Apple to be trustworthy, for reasons given on page 360.

Cost of Machine Mixing and Wagon Hauling.—Mr. G. D. Fisher. Asst. Engr., The Laclede Gas Light Co., St. Louis, has given the following data on the mixing, delivering and placing of Portland cement concrete for a pavement base 6 ins. thick.

The gravel was dumped from wagons into a large hopper, raised by a bucket elevator into bins, and drawn off through gates into receiving hoppers on the charging platform where the cement was added. The receiving hoppers discharged into the mixers, which discharged the mixed concrete into a loading car that dumped into wagons, which delivered it on the street where wanted. The longest haul in wagons was 30 mins., but careful tests showed that the concrete had hardened well. The wagons were patent dump wagons of the drop-bottom type.

Mr. Fisher says:

"You may consider the following figures a fair average of the plant referred to, working to its capacity. To these amounts, however, must be added the interest on the investment, the cost of wrecking the plant and the depreciation of the same, superintendence, and the pay roll that must be maintained in wet weather. I am assuming the street as already brought to grade and rolled.

"With labor at $1.75 per day of 10 hrs., teams at $4, engineer and foremen at $3, and engine at $5 per day, concrete mixed and put in place by the above method costs:

	Per cu. yd.
To mix	$0.12 to $0.15
To deliver to street	0.10 to 0.14
To spread and tamp in place	0.08 to 0.11
Total	$0.30 to $0.40

[illegible] Contractors' Supply [illegible] said by Munici- [illegible]

[illegible] mixed batches per [illegible]

[illegible] every 2 minutes, [illegible] as by this [illegible] owing to [illegible]

[illegible] efficiency can be [illegible]

[illegible] a Contin- [illegible] the base for [illegible] mechanical mix- [illegible] great rapidity [illegible] is possible where [illegible]

[illegible] was used. This [illegible] Elmira, N. Y., and [illegible] N. Y. and is of the con- [illegible] measuring device, [illegible] cement, sand and stone [illegible] mounted on trucks, [illegible] comparatively [illegible] plank and [illegible] like manner [illegible] hopper on the other [illegible] a man who [illegible] the mixer.

[illegible] is done auto- [illegible] machine itself, so that [illegible] men keep the hop- [illegible]

[illegible] the sand [illegible] to a drag [illegible] two men shov- [illegible] was hauled [illegible] made by the J. E. [illegible] was very enthusiastic [illegible] men and 2 to 4 [illegible] sq. yds. [illegible] laborers at 15 cts. [illegible] of labor was [illegible] of concrete base [illegible] did not add 1 ct. [illegible] was set up on a side [illegible] for a distance of a [illegible] were used, but as

[illegible]

the concrete approached the mixer, less hauling was required, and finally only 2 carts were used.

The Briggs cart is provided with an ingenious dumping device that is operated by the driver, who does not leave the horse's head to dump the cart. As is customary with all one-horse carts on short haul work, the driver leads the horse. The cart dumps from the bottom and spreads the load in a layer about 8 or 9 ins. thick, so that no greater amount of spreading with shovels is necessary than where the concrete is delivered in wheelbarrows. Another feature about the cart that is worthy of mention is the fact that no appreciable amount of the material leaks out, even when the concrete is mixed very wet. It takes about 20 seconds for a cart to back up and get its load and about 5 seconds to dump and spread the load.

On another job where wheelbarrows were used for conveying the concrete, the gang was organized as follows:

8 men loading and wheeling gravel in barrows.
2 men assisting in loading gravel into barrows.
1 man dumping barrows into hopper.
3 men loading and wheeling sand.
1 man dumping barrows into hopper.
7 men wheeling concrete in barrows.
3 men spreading concrete.
2 men tamping concrete.
1 man opening cement and filling buckets.
1 man pouring cement into hopper.
1 man operating mixer.
1 man shoveling up concrete spilled at outlet of mixer in loading barrows.
1 engineman.

32 Total.

In dumping the wheelbarrows into the hopper, one man assisted the barrow men at each of the two side hoppers. The wheelbarrow loads of concrete were very small, probably not more than 1 cu. ft. and were wheeled only a short distance over the dirt. The mixer was moved forward at frequent intervals, the stock piles of sand and gravel being continuous piles dumped in advance along the street, sand on one side, gravel on the other side of the street.

Portland cement concrete was used in the proportion of 1 : 3 : 6.

The average day's output of this gang was 150 cu. yds., or 900 sq. yds., in 8 hrs.; but on the best day's work the output was 200 cu. yds., or 1,200 sq. yds., in 8 hrs., which is a remarkable record for 32 men and a mixer working only 8 hrs.

When one remembers that an excellent day's work is 3 cu. yds. of concrete per man, where no mixer is used, and that 2 to 2½ cu. yds. is a more common record for hand work on streets, we realize that concrete mixers are bound to become universally used on street work in the very near future, for a mixer practically doubles the output of every man, if the work is properly handled with a mixer adapted to the purpose.

Cost of Concrete Pavement, Windsor, Ont.*—Concrete pavement

**Engineering-Contracting,* Nov. 20, 1907.

is constructed in all essential respects like cement sidewalk. The subsoil is crowned and rolled hard, then drains are placed under the curbs; if necessary to secure good drainage a subbase of gravel, cinders or broken stone 4 to 8 ins. thick is laid and compacted by rolling. The foundation being thus prepared a base of concrete 4 to 5 ins. thick is laid and on this a wearing surface 2 to 3 ins thick.

In constructing concrete pavement at Windsor, Ont., the street is first excavated to the proper grade and crown and rolled with a 15-ton roller. Tile drains are then placed directly under the curb line and a 6 x 16-in. curb is constructed, using 1 : 2 : 4 concrete faced with 1 : 2 mortar. Including the 3-in. tile drain this curb costs the city by contract 38 cts. per lin. ft. The pavement is then constructed between finished curbs.

The fine profile of the subgrade is obtained by stretching strings from curb to curb, measuring down the required depth and trimming off the excess material. The concrete base is then laid 4 ins. thick. A 1 : 3 : 7 Portland cement concrete is used, the broken stone ranging from ¼ in. to 3 ins. in size, and it is well tamped. This concrete is mixed by hand and as each batch is placed the wearing surface is put on and finished. The two layers are placed within 10 mins. of each other, the purpose being to secure a monolithic or one-piece slab. The top layer consists of 2 ins. of 1 : 2 : 4 Portland cement and screened gravel, ¼ in. to 1 in., concrete. This layer is put on rather wet, floated with a wooden float and troweled with a steel trowel while still wet. Some 20,500 sq. yds. of this construction have been used and cost the city by contract:

	Per sq. yd.
Bottom 4-in. layer 1 : 3 : 7 concrete	$0.57
Top 2-in. layer 1 : 2 : 4 concrete	0.32
Excavation	0.10
Total	$0.99

This construction was varied on other streets for the purpose of experiment. In one case a 4-in. base of 1 : 3 : 7 stone concrete was covered with 2 ins. of 1 : 2 : 2 gravel concrete. In other cases the construction was: 4-in. base of 1 : 3 : 7 stone concrete; 1½-in. middle layer of 1 : 2 : 4 gravel concrete and ½-in. top layer of 1 : 2 sand mortar. All these constructions have been satisfactory; the pavement is not slippery. The cost to the city by contract for the three-layer construction has in two cases been as follows:

Church St., 8,000 sq. yds.:	Per sq. yd.
4-in. base 1 : 3 : 7 concrete	$0.57
1½-in. 1 : 2 : 4 and ½-in. 1 : 2 mixture	0.32
Excavation	0.10
Total	$0.99

Albert and Wyandotte Sts., 400 sq. yds.:	Per sq. yd.
4-in. base 1 : 3 : 7 concrete	$0.66
1½-in. 1 :2 :4 and ½-in. 1 :2 mixture	0.39
Excavation	0.10
Total	$1.15

The cost of materials and rates of wages were about as follows:

Portland cement f. o. b. cars Windsor, per bbl.	$2.05
River sand, excellent quality, per cu. yd.	1.15
River gravel, screened, per cu. yd.	1.25
Crushed limestone, ¼ to 3 ins., per ton	1.15
Labor, per day	$1.75 to 2.00

At these prevailing prices the contractor got a fair profit at the contract price of $1.15; at 99 cts., any profit is questionable, according to City Engineer George S. Hanes, who gives us the above records. Expansion joints are located from 20 to 80 ft. apart and are filled with tar. Mr. Hanes writes that a large amount of this pavement will be built during 1908.

Cost of Excavating Concrete Base (Street Railway) and Laying New Concrete.*—In the spring of 1906 the United Railways Company, of St. Louis, Mo., undertook the reconstruction of six miles of its tracks on Olive St., in St. Louis. The reconstruction of these tracks is described by Mr. Richard McCulloch as follows:

Excavating Old Concrete Foundation.—In order to build the track it was necessary to make an excavation 21 ins. in depth in a concrete which had been setting for 18 years, and which experience in whatever excavations had been made had shown to be extremely hard. The method adopted for excavating the concrete was by blasting with small charges of dynamite, the object being to make these charges strong enough to shatter the concrete so that it could be taken out in large pieces, but not heavy enough to do other damage. Holes were drilled 7 to 8 ins. deep in the concrete, 10 ins. from the center of each rail, and 24 ins. apart, four holes coming between each pair of yokes. (The Olive St. line was at one time a cable road, a double cable track having been built for a distance of 3½ miles. In this construction a girder rail was laid on cast-iron yokes weighing 300 lbs. each, set in concrete 4 ft. apart. These yokes were 48 ins. in depth and inclosed a conduit for the cable 38 ins. in depth. In subsequent reconstructions when the road was converted into an electric line these yokes were left in place and the electric cars operated over the cable roadbed without change.) The hole was so located that the bottom of the hole was a little below the center of gravity of the section of concrete to be removed.

For drilling the holes there were used No. 2 Little Jap drills made by the Ingersoll-Rand Co., operated by compressed air at 90 lbs. pressure. This tool drills a 1.25-in. hole. A dry hole was drilled, the exhaust air from the hollow drill steel blowing the dust from the hole and keeping it clean. Common labor was used to run the drills and very little mechanical trouble was experienced. Three cars were fitted up, one for each gang, each car being equipped with a motor-driven air compressor, water for cooling the compressors being obtained from the fire plugs along the route. The air compressors were taken temporarily from those in use in the repair shops, no special machines being bought for the purpose. Electricity for

*Engineering-Contracting, Dec. 5, 1906.

operating the air compressor motors was taken from the trolley wire over the tracks. The car was moved along as the holes were drilled, air being conveyed from the car to the drills through a flexible hose. Two drills were operated normally from each car. One of the air compressors was exceptionally large and at times operated four drills.

The total number of holes drilled in the reconstruction of the track was 31,000. The total feet of hole drilled was 20,700 ft. The following figures give the average performance of the best one of the drilling outfits, which operated from two to three drills:

Depth of hole	8 ins.
Number of holes per hour per drill	30
Feet of hole drilled per hour per drill	20.3
Labor cost per foot of hole drilled	$0.027
Labor cost of drilling per cu. yd. blasted	$0.085
Drilling cost per lin. ft. of track	$0.017
Drilling cost per mile of track	$89.76

In these figures there is no charge for electric power or for depreciation of machinery.

For blasting, a 0.1-lb. charge of 40 per cent dynamite was used in each hole. A fulminating cap was used to explode the charge, and 12 holes were shot at one time by an electric firing machine. The dynamite was furnished from the factory in 0.1-lb. packages, and all the preparation necessary on the work was to insert the fulminating cap in the dynamite, tamp the charge into the hole and connect wires to the firing machine. In order to prevent any damage being done by flying rocks at the time of the explosion, each blasting gang was supplied with a cover car, which was merely a flat car with a heavy bottom and side boards. When a charge was to be fired, this car was run over the 12 holes and the side boards let down, so that the charge was entirely covered. This work was remarkably free from accidents. There were no personal accident claims whatever, and the total amount paid out for property damages for the whole six miles of construction was $685. Most of this was for glass broken by the shock of explosion. There was no glass broken by flying particles. The men doing this work, few of whom had ever done blasting before, soon became very expeditious in handling the dynamite, and the work advanced rapidly. The report made by the firing of the 12 holes was no greater than that made by giant firecrackers.

For the drilling and blasting the old rail had been left in place to carry the aim compressor car and the cover car. After the blasting, this rail was removed and the concrete excavated to the required depth. In most cases the cable yokes had been broken by the force of the blast. Where these yokes had not been broken, they were knocked out by blows from pieces of rail. The efficacy of the blasting depended largely upon the proper location of the hole. Where the holes had been drilled close to the middle of the concrete block, so that the dynamite charge was exploded a little below the center of gravity of the section, the concrete was well shattered and could be picked out in large pieces. Where the hole had been located too close to either side of the concrete block, however, the

charge would blow out at one side and a large mass of solid concrete would be left intact on the other side. The total estimated quantity of concrete blasted was 6,558 cu. yds., or 0.2 cu. yds. of concrete per lineal foot of track. The cost of the dynamite delivered in 0.1-lb. packages was 13 cts. per lb. The exploders cost $0.0255 each.

The following data represent the average work of the three gangs working on the westbound track between 14th St. and Boyle Ave.:

Cost of dynamite charge per hole	$0.013
Cost of exploder per hole	$0.0255
Four holes blasted in each 4 ft. of track:	
Lin. ft. of track blasted per hour	138
Cu. yds. of concrete blasted per hour	27.6
Cu yds. of concrete blasted per lb of dynamite	2
Labor cost per cu. yd. blasted	$0.076
Cost dynamite and exploders per cu. yd. blasted	$0.192
Cost labor and material per cu. yd. blasted	$0.268
Cost blasting per lin. ft. of track	$0.054
Cost blasting per mile of track	$285.12
Cost drilling and blasting per cu. yd	$0.353
Cost drilling and blasting per lin. ft. of track	$0.071
Cost drilling and blasting per mile of track	$374.88

When the excavation was completed, the ties were placed in the trench, the rail spiked down, the tie rods pulled up to gage and temporary fishplates put on the joints. Work trains were then run on this track and the excavated material hauled away. The excavated material in this job amounted to 11,410 cu. yds., or 0.348 cu. yd. per lineal foot of track. The United Railways Company purchased a sink hole and completely filled it with excavated material. All excavated material and all new material with the exception of the cement used in this work was handled on cars, no teams being used at all. It would have been impossible to do the work in the time occupied had wagons and teams been depended upon.

The ties were of hewn cypress, 6 ins. x 8 ins., in sections, and 7 ft. long, and were spaced 2 ft. between centers. Tie plates were used under the rail, each alternate tie plate being a brace plate. The rail used weighed 112 lbs. per yard and was furnished in 60-ft. lengths.

Mixing and Placing New Concrete.—After the excavated material had been hauled away and the street cleaned up, the track was lined and surfaced by means of wooden blocks and wedges placed beneath the ties. Concrete was then tamped beneath and around the ties, the concrete being deposited in the track from a concrete mixing machine running on the rails. The concrete used was composed of a mixture by volume of 1 part of Portland cement, 2½ parts of river sand and 6½ parts of crushed limestone rock. The cost (delivered) of the materials composing this concrete was as follows:

Crushed rock	$2.85 per square	= $0.0285 per cu. ft. = 0.77 per cu. yd.
Sand	$2.50 per square	= 0.025 per cu. ft. = 0.675 per cu. yd.
Portland cement	$1.70 per barrel	= 0.425 per sack.

For the track work, 7.36 cu. ft., or 0.273 cu. yd., were required per

lineal foot of track, 1¼ sacks of cement per lineal foot of track, or 1,650 bbls. of cement per mile of track, were used in this work.

The value of the cement, rock and sand used was $0.108 per cu. ft. of concrete, or $2.92 per cu. yd. of concrete.

The material for the concrete was distributed on the street beside the tracks in advance of the machine, the sand being first deposited, then the crushed rock piled on that, and finally the cement sacks emptied on top of this pile. The materials were shoveled from this pile into the concrete mixing machine without any attempt at hand mixing on the street. Great care was taken in the delivery of materials on the street to have exactly the proper quantity of sand, rock and cement, so that there would be enough for the ballasting of the track to the proper height and that none would be left over. Each car was marked with its capacity in cubic feet, and each receiver was furnished with a table by which he could easily estimate the number of lineal feet of track over which the load should be distributed.

The concrete mixing machines were designed and built in the shops of the United Rys. Co. Three machines were used in this work, one for each gang. The machine is composed of a Drake continuous worm mixer, fed by a chain dragging in a cast-iron trough. The trough is 36 ft. long, so that there is room for fourteen men to shovel into it. Water is sprayed into the worm after the materials are mixed dry. This water was obtained from the fire plugs along the route. In the first machine built, the Drake mixer was 8 ft. long. In the two newer machines the mixer was 10 ft. long. Both the conveyor and the mixer were motor driven, current being obtained for this purpose from the trolley wire overhead. Two types of machines were used, one in which the conveyor trough was straight and 45 in. above the rail, and the other in which the conveyor trough was lowered back of the mixer, being 25 in. above the rail. The latter type had the advantage of not requiring such a lift in shoveling, but the trough is so low that a motor truck cannot be placed underneath it. In the high machine the mixer is moved forward by a standard motor truck under the conveyor. In the low machine the mixer is moved by a ratchet and gear on the truck underneath the mixer. A crew of 27 men is required to work each machine, and under average conditions concrete for 80 lin. ft. of single track, amounting to 22 cu. yds., can be discharged per hour. The following figures give the average performance of the three machines in concreting the westbound track from 14th St. to Boyle Ave.:

Number men employed at machine	27
Number men shoveling into machine	14
Lin. ft. track concreted per hour	80.95
Cu. ft. concrete discharged per hour	595.79
Cu. yd. concrete discharged per hour	22.06
Labor cost concrete per lin. ft. of track	$0.071
Labor cost concrete per cu. yd.	$0.26
Cost of materials composing concrete per lin. ft. of track	$0.791
Cost of materials composing concrete per cu. yd.	$2.92

Total cost of concrete (labor and material) per lin. ft. of track	$0.862
Total cost of concrete (labor and material) per cu. yd.	$3.18
Total cost of concrete (labor and material) per mile of single track	$4,551.36

In these figures there is no charge for electric power or for depreciation.

The section between 14th St. and Boyle Ave. (5.51 miles long) was divided into three sections, and three foremen, with independent gangs, were put on each section. Work was carried on day and night. The Olive St. line is a double-track road, and during construction one track was kept open for traffic in one direction. Cars going in the opposite direction were sent by another route.

The work was begun April 30, 1906, and the cars were turned back on the street, exactly six weeks having elapsed since ground was broken. Of this time two weeks were allowed for the setting of the concrete, so that the entire work, with the exception of paving, was done in four weeks, an average of 1,040 lin. ft. of single track per day. The cost of this 5½ miles of track was about $170,500. For the entire work, after allowing for scrap material from the old track, the average cost per mile was about $27,000.

Cost of Excavating an Asphalt Pavement and Its Concrete Base.*—In relaying a street car track it was necessary to excavate the pavement between the rails, and for two feet outside the rails. The pavement was asphalt 2½ ins. thick laid on a concrete base 9 ins. thick. The concrete was made with natural cement and was consequently by no means as difficult to excavate as it would have been if Portland cement had been used.

In taking up the asphalt between the tracks it was found that the progress depended very much upon the temperature of the day. On cool days when the asphalt was brittle and the men worked rapidly, it was possible for three men to excavate 4,800 sq. ft. between the tracks in 10 hours. This is equivalent to nearly 180 sq. yds. per man per day. Of course, it was not necessary to cut the asphalt loose from the rails on each side, so the work consisted merely in prying up the asphalt with crow bars and breaking it with a sledge. Two men pried the asphalt up, while a third man used the sledge, and cast the pieces aside ready to be hauled away.

During most of the time, however, the asphalt was hot enough not to be brittle, and had to be cut up with a grub ax. In that case two men would pry up the asphalt, using picks, while the third man would cut off a strip 1½ ft. wide and as long as the distance between the tracks. Then he would cut this strip in two pieces with the grub ax. In the meantime the two men with the picks would be prying up some more of the asphalt. These three men worked very deliberately and averaged 1,700 sq. ft. per day. This is

**Engineering-Contracting*, Sept. 19, 1906.

equivalent to 63 sq. yds., or 4¼ cu. yds. per man per day. Wages were $1.75, hence the cost of excavating the asphalt was 2¾ cts. per sq. yd., or 40 cts. per cu. yd. This does not include the cost of loading and hauling it away.

In excavating the strip 1 ft. wide outside the rails, it was, of course, necessary to cut through the asphalt along a line parallel with the rail and 1 ft. away. To do this cutting a chisel having a bit 3 ins. wide and provided with a handle, was held by one man while a second man struck it with a sledge. These two men, when working rapidly, would cut 1,200 lin. ft. in 10 hours; hence one man cut 600 lin. ft., thus loosening 600 sq. ft. of asphalt ready to be pried up. A third man would pry up the asphalt with a pick and cut it off in sections, and he averaged 600 sq. ft. a day, working very deliberately. Hence the average output of each of the three men was 300 sq. ft., or 33 sq. yds., per man per day, cut out, pried up, and cast aside. This is equivalent to a little more than 2¼ cu. yds. per man per day, and the cost was 75 cts. per cu. yd., or 5¼ cts. per sq. yd.

As above stated, the concrete was 9 ins. thick and was made with natural cement. It was loosened with picks, usually without great difficulty, and was shoveled aside ready to be hauled away. Each laborer averaged 3 cu. yds., or 12 sq. yds. per day. Hence the cost was practically 60 cts. per cu. yd., or 15 cts. per sq. yd. To this should be added the cost of loading into wagons, which was 16 cts. per cu. yd., or 4 cts. per sq. yd. The cost of hauling depends upon distance to be hauled, and can be easily estimated for any given conditions.

Amount of Materials Required for Cement Sidewalk Construction.* — The great majority of cement sidewalks come within the range of 3 ins. to 7 ins. in thickness; the most common base mixtures are 1 : 2 : 5 and 1 : 3 : 6 and the most common finishing mixtures are 1 : 1, 1 : 1½ and 1 : 2. The accompanying tables have been computed to give by simple arithmetic, the volume of concrete, and the quantities of cement, sand and stone required per 100 sq. ft. of sidewalk, ranging from 3 ins. to 7 ins. thick and constructed of the above named mixtures. Table XVII gives separately the volume of base concrete and of surfacing mortar in 100 sq. ft. of walk of the different thicknesses; Table XVIII gives for each of the thicknesses and mixtures named the amount of cement, sand and stone required per 100 sq. ft.

The tables have been calculated on the assumption that—the cement being measured loose as is usual in sidewalk work—a barrel of cement measures 4.4 cu. ft. For finishing mortar the voids in the sand amount to 45 per cent; for base concrete the voids are assumed to be 40 per cent for sand and 45 per cent for broken stone. On these assumptions according to the theory of proportioning and the tables of mortar given in the section on Concrete, the

*Engineering-Contracting, Nov. 4, 1908, and Jan. 13, 1909.

TABLE XVIII.—SHOWING QUANTITIES OF CEMENT, SAND AND BROKEN STONE REQUIRED FOR 100 SQ. FT. OF SIDEWALK SEPARATELY FOR BASE AND FOR SURFACE FINISH FOR DIFFERENT PROPORTIONS OF CONCRETE AND DIFFERENT THICKNESSES OF WALK.

Thickness, ins.	—1 : 2 : 4— Cem., bbls.	Sand, cu.yds.	Stone, cu.yds.	—1 : 2 : 5— Cem., bbls.	Sand, cu.yds.	Stone, cu.yds.	—1 : 3 : 6— Cem., bbls.	Sand, cu.yds.	Stone, cu.yds.	Thickness, ins.	—1 : 1— Cem., bbls.	Sand, cu. yds.	—1 : 1½— Cem., bbls.	Sand, cu. yds.	—1 : 2— Cem., bbls.	Sand, cu. yds.
2½	1.00	0.32	0.65	0.89	0.29	0.73	0.69	0.34	0.68	½	0.61	0.093	0.52	0.124	0.45	0.139
3	1.20	0.39	0.78	1.08	0.35	0.88	0.84	0.41	0.82	¾	0.91	0.139	0.77	0.186	0.67	0.209
3½	1.40	0.45	0.91	1.25	0.41	1.02	0.97	0.47	0.95	1	1.12	0.185	1.03	0.247	0.90	0.278
4	1.61	0.52	1.04	1.43	0.47	1.18	1.12	0.55	1.09	1¼	1.52	0.232	1.29	0.308	1.12	0.347
4½	1.80	0.58	1.17	1.61	0.53	1.32	1.25	0.61	1.22	1½	1.83	0.278	1.55	0.371	1.34	0.418
5	2.02	0.65	1.30	1.79	0.59	1.47	1.39	0.68	1.36	1¾	2.03	0.325	1.81	0.433	1.57	0.487
6	2.45	0.78	1.57	2.17	0.71	1.78	1.58	0.82	1.64	2	2.33	0.371	2.06	0.494	1.79	0.556

amount of materials per cubic yard of mortar and of concrete are as follows:

Mortar proportions:	1:1	1:1½	1:2
Barrels of cement	3.94	3.34	2.90
Cubic yards of sand	0.6	0.8	0.9
Concrete proportions:	1:2:5		1:3:6
Barrels cement	1.16		0.90
Cubic yards sand	0.38		0.44
Cubic yards stone	0.95		0.88

Table XVIII has been computed from the above quantities and those given in Table XVII; thus for a 3-in. base (Table XVII) 0.93 cu. yd. of concrete is required per 100 sq. ft.; if the base be a 1 : 2 : 5 mixture, then the

Cement = 0.93 cu. yd. × 1.16 bbl. = 1.08 bbl.

Sand = 0.93 cu. yd. × 0.38 cu. yd. = 0.35 cu. yd.

Stone = 0.93 cu. yd. × 0.95 cu yd. = 0.88 cu. yd.

The final results are the quantities given in Table XVIII, and the other quantities given in this table are obtained in a similar manner.

TABLE XVII.—SHOWING VOLUME OF CONCRETE BASE AND MORTAR WEARING SURFACE PER 100 SQ. FT. OF CEMENT WALK OF VARIOUS THICKNESSES.

—Concrete Base.—		—Mortar Wearing Surface.—	
Thickness, ins.	Volume, cu. yds.	Thickness, ins.	Volume, cu. yds.
2½	0.77	½	0.155
3	0.93	¾	0.232
3½	1.08	1	0.309
4	1.24	1¼	0.386
4½	1.39	1½	0.464
5	1.55	1¾	0.541
6	1.87	2	0.618

Note.—100 sq. ft. of walk 1 in. thick has a volume of 0.309 cu. yd. To get the volume in a walk of any thickness, multiply 0.309 by the thickness of the walk in inches, e. g., 0.309 cu. yd. × 6 ins. = 1.87 cu. yd.

Table XVIII is used in estimating as follows:

Problem: Find the amount of cement, sand and stone required for 1,000 ft. of sidewalk, 5 ft. wide; base 4 ins. thick of 1 : 2 : 5 concrete; wearing surface 1 in. thick of 1 : 1½ mortar.

From Table XVIII we have:

Per 100 sq. ft.	Cement. bbls.	Sand. cu. yds.	Stone. cu. yds.
Base, 4 ins.	1.43	0.47	1.18
Wearing surface 1 in.	1.03	0.247	....
Total per 100 sq. ft.	2.46	0.717	1.18
	50*	50	50
Total per 5,000 sq. ft.	123.00	35.850	59.00

*1,000 × 5 = 5,000 ÷ 100 = 50.

Cost of Cement Walks.—The cost of cement walks is commonly estimated in cents per square foot, including the necessary excavation and the cinder or gravel foundation. The excavation usually costs about 13 cts. per cu. yd., and if the earth is loaded into wagons the loading costs another 10 cts. per cu. yd., wages being 15 cts. per hr. The cost of carting depends upon the length of haul, and may be estimated from data given on page 121. If the total

cost of excavation is 27 cts. per cu. yd., and if the excavation is 12 ins. deep we have a cost of 1 ct. per sq. ft. for excavation alone. Usually the excavation is not so deep, and often the earth from the excavation can be sold for filling lots.

The base of the walk is often made 3 ins. thick, of 1 : 3 : 6 concrete, and the top wearing coat is often made 1 in. thick of 1 : 1½ mortar. The cement is invariably Portland.

Such a walk is frequently laid on a foundation of gravel or cinders 4 ins. thick.

And by using the table on page 443, we can estimate the quantity of cement required for any given mixture.

As the average of a number of small jobs, my records show the following costs per sq. ft. of 4-in. walk such as just described:

	Cts. per sq. ft.
Excavating 8 ins. deep	0.65
Gravel for 4-in. foundation, at $1.00 per cu. yd.	1.20
0.018 bbl. cement, at $2.00	3.60
0.009 cu. yd. broken stone, at $1.50	1.35
0.006 cu. yd. sand, at $1.00	0.60
Labor making walk	1.60
Total	9.00

This is 9 cts. per sq. ft. of finished walk. The gangs that built the walk were usually 2 masons at $2.50 each per 10-hr. day with 2 laborers at $1.50 each. Such a gang averaged 500 sq. ft. of walk per day.

Cost of Cement Walk.*—The following notes, based on actual experience, relative to the cost of a walk, are taken from a pamphlet prepared by Mr. C. W. Boynton and published by the Universal Portland Cement Co. Experience has shown that a gang of six men can lay between 600 and 800 sq. ft. of walk in a day of 10 hrs. and 700 sq. ft. is considered as a day's work in arriving at the figures given below. This estimate is based on a 6-ft. walk having a 4-in. base, consisting of 1 part cement, 2½ parts sand and 5 parts crushed stone, covered with a ¾-in. top of 1 part cement and 1½ parts sand. The stone ranged in size from ¼-in. to ¾-in. and contained 48% voids. A good grade of lake sand passing a ¼-in. screen was used. The sand contained 36% voids. The mixing was done by hand, and the cost of materials includes delivery on the work. The costs were as follows:

Labor:	
One finisher at $5 per day	$ 5.00
Five laborers at $2 per day	10.00
Total, 700 sq. ft. at 2.14 cts.	$15.00
Materials:	
Cement, 2.5 bbls. at $2.00	$ 5.00
Stone, 1.11 cu. yds. at $1.50	1.66
Sand, .77 cu. yds. at $1.00	.77
Cinders, 2.7 cu. yds. at 50c	1.35
Total cost materials for 100 sq. ft. at 8.78 cts.	$ 8.78
Total labor and materials, per sq. ft, 10.92 cts.	

*Engineering-Contracting, Aug. 26, 1908.

It should be noted that this estimate provides for a walk where an excavation for the sub-base was necessary.

Cost of Cement Walks in Iowa.—Mr. L. L. Bingham sent out letters to a large number of sidewalk contractors in Iowa asking for data of cost. The following was the average cost per square foot as given in the replies:

	Cts. per sq. ft.
Cement, at $2 per bbl.	3.6
Sand and gravel	1.5
Labor, at $2.30 per day (average)	2.2
Incidentals, estimated	0.7
Total per sq. ft.	8.0

This applies to a walk 4 ins. thick, and includes grading in some cases, while in other cases it does not. Mr. Bingham writes me that in this respect the replies were unsatisfactory. He also says that the average wages paid were $2.30 per man per day. It will be noted that a barrel of cement makes 55½ sq. ft. of walk, or it takes 1.8 bbls. per 100 sq. ft.

The average contract price for a 4-in. walk was 11½ cts. per sq. ft.

Cost of Cement Walk, San Francisco.—Mr. George P. Wetmore, of the contracting firm of Cushing & Wetmore, San Francisco, gives the following:

The foundations of cement walks in the residence district of San Francisco are 2½ ins. thick, made of 1:2:6 concrete, the stone not exceeding 1 in. in size. The wearing coat is ½ in. thick, made of 1 part cement to 1 part screened beach gravel. The cement is measured loose, 4.7 cu. ft. per bbl. The foundation is usually laid in sections 10 ft. long; the width of sidewalks is usually 15 ft. The top coat is placed immediately, leveled with a straight edge and gone over with trowels till fairly smooth. After the initial set and first troweling, it is left until quite stiff, when it is troweled again and polished—a process called "hard finishing." The hard finish makes the surface less slippery. The surface is then covered with sand, and watered each day for 8 or 10 days. The contract price is 9 to 10 cts. per sq. ft. for a 3-in. walk; 12 to 14 cts. for a 4-in. walk having a wearing coat ¾ to 1 in. thick. A gang of 3 or 4 men averages 150 to 175 sq. ft. per man per day of 9 hrs. Prices and wages are as follows:

Cement, per bbl.	$2.50
Crushed rock, per cu. yd.	1.75
Gravel and sand for foundation, per cu. yd.	1.40
Gravel for top finish, per cu. yd.	1.75
Finisher wages, best, per hr.	0.40
Finisher helper, best, per hr.	0.25
Laborer, best, per hr.	0.20

Cost of Cement Sidewalks, Toronto, Ont.*—A considerable part of the public improvement work of Toronto, Ont., is done by day labor under the supervision of the city engineer. In the following article is given the actual unit costs of the construction of 4½-in. concrete sidewalks, 4 ft. and 6 ft. wide, built by day labor.

*_Engineering-Contracting_, Aug. 29, 1906.

The sidewalks have a 4-in. foundation of coarse gravel or soft coal cinders, thoroughly consolidated by pounding or rolling, upon which is placed a 3½-in. layer of concrete, composed of 1 part Portland cement, 2 parts of clean, sharp, coarse sand, and 5 parts of approved furnace slag, broken stone or screened gravel. The wearing surface is 1 in. thick and is composed of 1 part Portland cement, 1 part of clean, sharp, coarse sand and 3 parts of screened pea gravel, crushed granite, quartzite or suitable hard limestone.

COST OF 6-FT. SIDEWALK.

	Per sq. ft.
Labor	5.59 cts.
0.016 bbls. cement, at $1.54	2.49 cts.
0.027 cu. yds. gravel, at $0.80	2.21 cts.
0.0046 cu. yds. sand, at $0.80	0.37 cts.
Water	0.05 cts.
Total	10.71 cts.

COST OF 4-FT SIDEWALK.

	Per sq. ft.
Labor	6.73 cts.
0.0204 bbls. cement, at $1.54	3.15 cts.
0.0206 cu. yds. gravel, at $0.80	1.65 cts.
0.0049 cu. yds. sand, at $0.80	0.39 cts.
Water	0.07 cts.
Total	11.93 cts.

The rates of wages and the number of men employed were as follows:

1 foreman	$3.50 per day.
1 finisher	0.30 per hour.
1 helper	0.22 per hour.
15 laborers	0.20 per hour.

We are indebted to Mr. C. H. Rust, City Engineer of Toronto, Ont., for the above information.

Note how these labor costs are double what it costs a capable contractor to do the same class of work.

Cost of a Cement Walk, Forbes Hill Reservoir.—Mr. C. M. Saville, M. Am. Soc. C. E., gives the following data relating to 6,250 sq. ft. of cement walk built by contract:

Stone foundation	Per cu. yd.	Per sq. ft.
Broken stone for 12-in. foundation	$0.40	$0.015
Labor placing same, 15 cts. per hr.	1.50	0.056
Total	$1.90	$0.071
Concrete base (4½ ins. thick).		
1.22 bbls. cement per cu. yd., at $1.53	$1.87	$0.026
0.50 cu. yd. sand per cu. yd., at $1.02	0.51	0.007
0.84 cu. yd. stone per cu. yd., at $1.57	1.32	0.019
Labor (6 laborers and 1 team)	3.48	0.050
Total (for 90 cu. yds.)	$7.18	$0.102
Top finish (1 in. thick).		
4 bbls. per cu. yd., at $1.53	$6.12	$0.019
0.8 cu. yd. sand, at $1.00	0.80	0.002
Lampblack	0.29	0.001
Labor (2 walk masons and 1 helper)	6.36	0.016
Total	$13.57	$0.038
Grand total		$0.211

This walk was 6 ft. wide laid on a 12-in. foundation of broken stone. On top of this foundation was the concrete base, 5 ins. thick in the middle and 4 ins. thick at the sides. This base was surfaced with a top granolithic finish about 1 in. thick.

It is difficult to account for the high labor cost ($1.50) of placing the 12-in. stone foundation except on the supposition that the stones were broken by hand.

The work on the concrete base was unusually expensive, for no apparent reason except inefficiency of the men.

The two masons received $2.25 each per day, and their helper $1.50, and they averaged 360 sq. ft. per day, or 60 lin. ft. of walk 6 ft. wide, which is equivalent to 1⅝ cts. per sq. ft.

Atlas cement was used, and in measuring was assumed to be 3.7 cu. ft. per bbl.

It is perhaps useless to comment on the extravagantly large amount of stone used in the foundation.

Cost of Acid Finish on Cement Walk.*—In making 86,650 sq. ft. of cement walks (25 ft. wide), the South Park Commission of Chicago did the work by day labor (in 1908) at the following cost:

	Per sq. ft. Cts.
Cement, at $1.35 per bbl.	3.46
Sand and broken stone	4.70
Forms	0.39
Labor	3.70
Superintendence and tools (10% of above)	1.22
Total	13.47
Grading and filling with cinders	4.73
Finishing surface with acid	1.67
Grand total	20.17

The cement walk was 5 ins. thick (a 4-in. base of 1:2:4 concrete and a 1-in. surface of 1:2½), resting on 12 ins. of cinders. In spite of the fact that a machine mixer was used, the labor and superintendence on the cement work cost the very high sum of 4.92 cts. per sq. ft., which did not include the labor on the acid finish nor on the grading and cinders. This furnishes another example of an ill-advised attempt to "save the contractor's profits."

The cost of finishing 29,395 sq. ft. of the surface by acid was as follows:

	Total.	Per sq. ft. Cts.
10,800 lbs. (60 carboys) muriatic acid, at 1¼ cts.	$135.00	0.46
36 deck brushes, at 50 cts.	18.00	0.06
Labor	290.00	1.00
Add 10% for superintendence	44.00	0.15
Total	$487.00	1.67

*Engineering-Contracting, Dec. 9, 1908.

Cost of Cement Curb and Sidewalks, Gary, Ind.*—Mr. E. M. Scheflow gives the following:

The improvement of Madison St. at Gary, Ind., from the south line of the Wabash R. R. to the north line of the Pittsburg, Ft. Wayne & Chicago R. R., a distance of 3,800 ft., has been recently completed. The improvement consisted of brick pavement (see page 364 for cost), concrete curbs 5 ins. x 18 ins., with 5 ft. radii at street intersections and cement sidewalk 5½ ft. wide. The grading was all done during the winter while the ground was frozen and all the material was hauled at that time. These costs do not include grading.

Cost of Placing Curb.—The mixture for curbs was 1 : 3 : 5 Portland cement, torpedo sand and broken limestone, with a facing 1½ ins. thick composed of 1 : 1 : 3 of Portland cement, sand and granulated granite. The concrete was mixed dry by hand and then mixed wet in a worm screw mixer operated by a gasoline engine. Wooden forms were used.

The labor cost was as follows:

	Total.	Per lin. ft.
Laborers, mixing, 128 days, at $2.00	$256.00	$0.0351
Laborers, wheeling and tamping, 127 days, at $2	254.00	0.0348
Finishers, 51 days, at $5.50	280.50	0.0383
Form setters, 80 days, at $3	240.00	0.0330
Total, 7,268 lin. ft.	$1,030.50	$0.1412

Labor Cost of Laying Sidewalks.—The sidewalk was laid with a concrete foundation 3¾ ins. thick of the same proportions as that given for curbs and a wearing surface ¾ in. thick composed of five parts of Portland cement to seven parts of sand. The labor cost was as follows, the same method of mixing the concrete being used as for curbs:

	Total.	Per sq. ft.
Laborers, mixing, 117 days, at $2	$234.00	$0.0060
Laborers, wheeling, spreading and tamping, 142 days, at $2	284.00	0.0073
Finishers, 47 days, at $5.50	258.50	0.0066
Form setters, 37 days, at $3	111.00	0.0029
Total, 38,930 sq. ft.	$887.50	$0.0228

Cost of Cement Curb, Iowa.†—Data were given by Mr. M. G. Hall, in "Engineering News," April 2, 1908, relating to cement curb work. We have rearranged and analyzed the costs as follows. (For comments on the brick paving laid at the same time and place, see page 361.)

The cement curb material was mixed, 1 of cement to 3 of sand, in a ½-cu. yd. Smith mixer. The average cost of the three jobs, A, B and C, reduced to the same rates of wages, is given below. Job A was 2,000 lin. ft.; B was 10,000 lin. ft.; C was 20,000 lin. ft. The

*Engineering-Contracting, Oct. 14, 1908.

†Engineering-Contracting, June 23, 1909.

curb measured 5 x 18 ins. and was backed with cinders as shown in Fig. 13. The following costs are in cents per lin. ft.:

	Job A	Job B	Job C
Trenchmen, 20c per hr.	3.44	3.50	1.70
Form setters,, 35c per hr.	2.74	4.03	1.63
Filling cinders, 20c per hr.	0.47	0.62	0.50
Wheelers, 20c per hr.	0.58	0.68	0.50
Shovelers (concrete), 20c per hr.	....	....	0.50
Tampers, 20c per hr.	0.24	0.37	0.40
Finishers, 35c per hr.	0.42	0.70	0.56
Men on mixer, 22c per hr.	0.99	1.34	0.44
Removing forms, 20c per hr.	0.48	0.24	0.30
Backfilling, 20c per hr.	0.78	0.64	0.80
Miscellaneous, 20c per hr.	0.72	1.00	0.05
Water boy, 10c per hr.	0.33	0.31	0.20
Team and driver, 40c per hr.	3.86	3.71	0.50
Concrete wagon, 40c per hr.	....	....	1.20
Foreman, 35c per hr.	2.28	1.50	1.13
Total labor	17.33	18.62	10.41
Cement, at $1.40 bbl.	7.65	7.76	7.73
Sand, at $1.05 ton	3.45	3.51	3.50
Cinders	2.00	2.00	1.00
Total materials	13.10	13.28	12.23
Grand total	30.43	31.89	22.64

Since it takes 43 lin. ft. of 5 x 18-in. curb to make 1 cu. yd., the above items must be multiplied by 43 to reduce to a cubic yard basis. Omitting the items of trenching, backfilling and handling

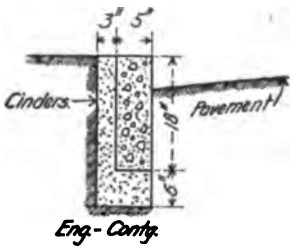


Fig. 13. Cement Curb.

cinders, we see that the labor on Job C cost 7.4 cts. per lin. ft., which is equivalent to $3.18 per cu. yd. of cement curb. The other two jobs were considerably more expensive, particularly in the items trenching and teaming.

None of the three was economically handled, as may be seen by comparison with the costs given on page 451, where the labor cost about half as much per cubic yard as on Job C, and far less than half as much as on Jobs A and B.

I would call attention to the fact that curbs often differ considerably in cross-section, and the labor of mixing and placing the concrete therefore differs materially when compared in terms of the

lineal foot as the unit. Hence all costs should also be reduced to the cubic yard basis also. When this is done, a contractor will frequently find that his work is not being handled with the expedition that it should be; for comparison with the cubic yard cost of other jobs of similar character may disclose to the contractor a weakness of management or laziness of men on his own job. This is well exemplified in the above costs recorded by Mr. Hall.

Cost of Cement Curb.*—The concrete curb shown in Fig. 14 was built at an average labor cost of 6 cts. per lin. ft. The labor force employed on the work was as follows:

	Per day.
8 laborers, at $1.75	$14.00
1 finisher, at $3.00	3.00
1 working foreman, at $4.00	4.00
Total, 350 lin. ft., at 6 cts.	$21.00

This force averaged 350 lin. ft. of curb per day of 10 hrs. For the body of the curb, 1¾ yds. gravel and 7 sacks of Portland cement in

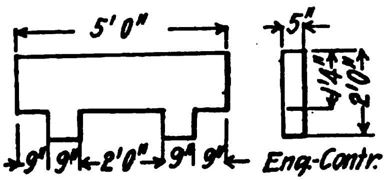


Fig. 14. Cement Curb.

a batch would make 60 lin. ft. of curb. For the outside finish a batch was made of 18 pails of screened gravel mixed with 4 sacks (12 pails) of Portland cement

The cost of the materials was as follows, not including the outside cement finish:

	Per lin. ft.
0.03 cu. yd. gravel, at $1.25	$0.0375
0.03 bbl. cement, at $2.40	0.0720
Total	$0.1075

For the above information we are indebted to Mr. A. W. Saunders, of Johnstown, Pa.

Cost of Cement Curb and Gutter.—The following costs were recorded by Mr. Charles Apple, and relate to work done at Champaign, Ill., in 1903. The work was done by contract, at 45 cts. per lin. ft. of the curb and gutter shown in Fig. 15.

The concrete curb and gutter was built in a trench as shown in the cut. The earth was removed from this trench with pick and shovel at a rate of 1 cu. yd. per man per hour. The concrete work was built in alternate sections, 7 ft. in length. A continuous line of planks was set on edge to form the front and back of the concrete

*Engineering-Contracting, June 10, 1908.

curb and gutter; and wood partitions, staked into place, were used The cost of the work was as follows:

COST OF CURB AND GUTTER.

	No. of men.	Lin. ft. per day.	Total wages.	Cost per 100 ft.
Opening trench, 18 x 30-in.	2	144	$3.50	$2.43
Placing and tamping cinders	2	350	3.50	1.00
Setting forms:				
Boss setter	1	...	3.00	...
Assistant setter	1	...	2.00	...
Laborer	1	...	1.75	...
Total setting forms	3	400	$6.75	$1.69
Mixing and placing concrete:				
Clamp man	1	...	$1.75	$0.50
Wheelers	3	...	5.25	1.50
Mixing concrete	4	...	7.00	2.00
Mixing finishing coat	2	...	3.50	1.00
Tampers	1	...	1.75	0.50
Finishing:				
Foreman and boss finisher	1	...	4.00	1.14
Assistant finisher	1	...	3.00	0.88
Water boy	1	...	.50	1.14
Total making concrete	14	350	$26.75	$ 7.64
Total for labor per 100 ft.				$12.76
Materials for 100 lin. ft.:		Quantity.	Price.	
Portland cement		8¼ bbls.	$1.85	$15.42
Cinders		7.5 yds.	.50	3.75
Gravel		2.5 yds.	1.00	2.50
Broken stone		2.5 yds.	1.40	3.50
Sand		1.0 yds.	1.00	1.00
Total for material per 100 ft.				$26.17
Total for material and labor per 100 ft.				$38.93

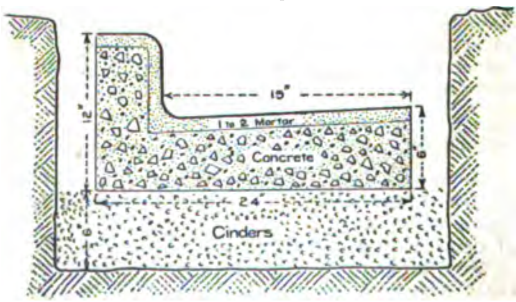


Fig. 15. Cement Curb and Gutter.

This is the total cost, exclusive of lumber, tools, interest, profits, etc., and it is practically 40 cts. per lin. ft.

In 100 lin. ft. of curb and gutter there were 4.6 cu. yds. of concrete and mortar facing, 4 cu. yds. of which were concrete; hence the 9 men in the concrete gang laid 14 cu. yds. of concrete per day, whereas the 4 men mixing and placing the mortar finishing laid

only 2½ cu. yds. of mortar per day, assuming that the mortar finishing averaged just 1 in. thick. Since these 4 men (2 mixers and 2 finishers) received $10.50 a day, it cost more than $4 per cu. yd. to mix and place the 1:2 mortar, as compared with $1.41 per cu. yd. for mixing and placing the concrete. The concrete was built in alternate sections 7 ft. long. The 3 men placing forms averaged 400 lin. ft. a day, so that the cost of placing the forms was $1 per cu. yd. of concrete. The 2 men placing and tamping cinders averaged 16 cu. yds. of cinders per day, or 8 cu. yds. per man. This curb and gutter was built by contract at 45 cts. per lin. ft.

For several jobs, in which a curb and gutter essentially the same as shown in Fig. 15 was built, my records show a general correspondence with the above given data of Mr. Apple. Our work was done with smaller gangs, 1 mason and 2 laborers being the ordinary gang. Such a gang would lay 80 to 100 lin. ft. of curb and gutter per 10-hr. day, at the following cost:

1 mason, at $2.50	$2.50
2 laborers, at $1.50	3.00
Total	$5.50

This made a cost of 5½ to 7 cts. per lin. ft. for labor, and it did not include the cost of digging a trench to receive the curb and gutter.

Cost of Cement Curb, Baltimore, Md.—I give the following abstract from an article in *Engineering-Contracting*, Sept. 22, 1909, merely to show how high the cost of a cement curb may be when built by day labor instead of by contract. This work was done in Baltimore, in 1908, by city forces, at the following cost:

	Per lin. ft.
0.037 cu. yd. crushed stone, at $1.75	$0.065
0.02 cu. yd. sand, at $0.80	0.015
0.05 bbl. cement, at $1.29	0.064
Total concrete materials	$0.144
Wainwright iron bar	0.150
Frogs	0.010
Total materials	$0.304
Labor	0.506
Grand total	$0.810

The gang engaged in making this curb was as follows per 8-hr. day:

	Per day.
1 foreman	$ 4.00
1 finisher	2.50
3 laborers, at $1.66⅔	5.00
1 cart, horse and driver	2.50
Total, 28 lin. ft., at 50 cts.	$14.00

The curb measured 6 ins. thick by 24 ins. high, or 1 cu. ft. per lin. ft., and the concrete was mixed 1 : 2½ : 5. Since the labor cost 50 cts. per lin ft., this is equivalent to $13.50 per cu. yd.! So far as I know, this breaks all records for high cost of cement curb work. Of course the "contractors' profits" were saved.

Cost of Cement Curb and Gutter, Ottawa, Ont.*—The method and cost of constructing 1,326 ft. of cement curb and gutter at Ottawa, Ont., are given in some detail by Mr. G. H. Richardson, Assistant City Engineer. We have remodeled the description and rearranged the figures of cost in the following paragraphs.

The concrete curb was built before doing any work on the roadway, and the first task was the excavation of a trench 2½ ft. wide and averaging 1 ft. 8 ins. in depth through light red sand. On the bottom of this trench there was placed a foundation of stone spalls 8 ins. thick; in width this foundation reached from 3 ins. back of the curb to 6 ins. beyond the front of the water table. The curb was made 5 ins. thick and ran from 10 ins. to 5½ ins. in height, and the water table was 14 ins. wide and 4 ins. thick, with a fall of 1¼ ins. from front to back. The concrete used was a mixture of 1 of Portland cement, 3 of sand, 3 of ⅝-in. screened limestone, and 4 of 2-in. stone. It was deposited in forms and tamped to bring the water to the face and then smoothed with a light troweling of stiff mortar.

The forms were constructed by first setting pickets and nailing to them a back board 2 ins. thick and 12 ins. wide and a front board 2 ins. thick and 6 ins. wide. The concrete for the water table was deposited in this form in sections and brought to surface by straight edge riding on wooden strips nailed across the form and properly set to slope, etc. After the water table had been troweled down and brushed a 1 x 10-in. board was set to mold the front face of the curb. This board was sustained by small "knee frames" made of three pieces of 1 x 2-in. stuff, one conforming to the slope of the water table and long enough to extend beyond the front of the 2 x 6-in. front board, a second standing plumb and bearing against the 1 x 10-in. face board, and the third forming a small corner brace between the two former to hold them in their proper relative positions. The 1 x 10-in. face board, etc., was separated from the 2 x 12-in, back board by a 5-in. block at each end, and then braced by the knee frames every 3 or 4 ft. In this way it was possible to bring this 1 x 10-in. board into perfect line by moving the knee braces in or out, and when correct nailing them to the 2 x 6-in. front board. The 1 x 10-in. face board being in position and braced and lined, the curb material was thoroughly tamped in, and when ready was troweled and brushed on the top, a small round being worked onto the top front corner with the trowel.

Expansion joints were provided for by building into the curb every 12 ft., a piece of ⅜-in. boiler plate, which was afterward withdrawn and the joint filled with sand and faced over. As soon as the concrete had set sufficiently the face board was taken down and face of curb finished and brushed, the fillet between curb and water table being finished to 2½ ins. radius. Circular curb and gutter of same construction was built at each corner, ½-in. basswood being used for forms, instead of 2 x 1-in. lumber.

**Engineering-Contracting*, Nov. 13, 1907.

In addition to the actual construction of curb and gutter the cost given below includes the cleaning up of the street, spreading or removal of all surplus material from excavation, and the extension of all sidewalks out to the curbs at the corners. It was also necessary to maintain a watchman on this work, which duty, under ordinary circumstances, would be done by the general watchman. The total length built was 1,326 ft., of which 1,209 ft. is straight and 117 ft. curved to a 12-ft. radius.

The rates of wages paid were $2 for horse and cart, $1.65 for watchman, and an average of $1.90 per day for labor, including foreman; all for nine hours' work per day. The working force consisted of 1 foreman, 1 finisher, 1 handy man, 4 concrete men, and 3 laborers, total 10 men.

The labor cost of the work was as follows:

Labor:	Total.	Per lin. ft. Cts.
Excavation and setting boards	$ 88.90	0.7
Laying stone foundation	43.30	3.3
Concreting	61.30	4.6
Finishing	45.15	3.4
Carting	9.85	0.76
Watchman	25.00	1.89
Clearing up	13.60	1.04
Extras (sidewalk extensions)	17.23	1.31
Total	$304.33	23.00

The cost of materials for curb and foundation were as follows:

Materials:	Total.	Per lin. ft. Cts.
171.112 tons spalls	$102.93	7.76
42 tons 2-in. stone	41.16	3.09
30.8 tons ⅝-in. stone	42.57	3.21
33,000 lbs. cement	161.70	12.19
24 cu. yds. sand	19.20	1.45
Total	$367.56	27.70

The cost of supplies and tools was as follows:

Supplies, Etc.:	Total.
1,000 ft. B. M. 2 x 12 boards charged off	$ 9.25
500 ft. B. M. 2 x 6 boards charged off	4.12
1,000 ft. B. M. 1 x 10 boards charged off	14.25
⅛-in. basswood	4.30
½ keg 3-in. nails	1.42
½ keg 4-in. nails	1.43
Pickets	3.25
Tools charged off	3.15
Total	$41.17

This total, when divided by 1,326 lin. ft. of curb, gives the cost per lineal foot as about 3 cts. We can now summarize as follows:

Item.	Total.	Per lin. ft.	P. C. of total.
Labor	$304.33	$0.23	43
Material	367.56	.28	51
Supplies	41.17	.03	6
Total	$713.06	$0.54	100

As indicated above, on more extensive work the costs of carting, watchman, cleaning up, and extras would be avoided. They cost

on this work 5 cts. and the work could therefore be done for 49 cts. if no such charges were included. On such work also the charge for supplies would be lower per foot and on any future work the labor cost could be materially lowered, this curb having been somewhat of an experiment as to method of construction. It is thought that with no charges for carting, cleaning, watchman, and extras, and with the experience obtained, this curb could be built for about 46 cts. The proportions adopted and the method of construction followed, produce a very strong, dense, homogeneous curb and gutter.

Cost of Setting Stone Curbs.—After the trench has been dug and foundation prepared, a mason and a helper will set 225 lin. ft. of stone curb in 10 hrs. If the mason receives 35 cts. per hr., and his helper receives 20 cts. per hr., the placing of the curb costs 2½ cts. per lin. ft. This cost is based upon the work of laying several thousand feet of dressed Medina sandstone curb, 24 ins. deep, and does not include any dressing of the stone. The men were not very efficient.

Cost of Cutting and Setting Granite Curb, N. Y.*—The work was done by a contractor on a New York City street, and involved the dressing and setting of 1,560 lin. ft. of granite curb. Each curb cutter cut 28½ lin. ft. of curb per day, and each curb setter set 184 lin. ft. per day. The labor cost was as follows:

	Per lin. ft.
0.0352 day curb cutter, at $4.00	$0.141
0.0058 day curb setter, at $4.00	0.023
0.0120 day curb setter's helper, at $2.00	0.024
Total	$0.188

These men were very inefficient or poorly managed.

Cost of Resetting Curb, N. Y.†—On Broadway, between 110th and 119th street, 2,253 lin. ft. of stone curb was set in 1904. Of this only 500 ft. was new curb, the rest being old curb that was taken up, dressed and reset. The work was done by a contractor, whose men worked an 8-hr. day, and the actual costs were as follows:

Excavation:	Rate per day.	Per lin. ft.
Foreman	$3.75	$0.004
Laborers	1.50	.020
Total per lin. ft.		$0.024
Concrete:	Rate per day.	Per lin. ft.
Foreman	$3.75	$0.004
Laborers	1.50	.026
Total per lin. ft.		$0.03
Setting and Dressing Curbs:	Rate per day.	Per lin. ft.
Stonecutters	$5.00	$0.12
Curb setters	4.00	.022
Curb setters' help	2.50	.025
Total per lin. ft.		$0.167

**Engineering-Contracting*, June 20, 1906.

†*Engineering-Contracting*, May 16, 1906.

It should be noted that in the table the excavation under curb is for the taking up of the old curb and making excavation for new curb.

The concrete for the curb foundation required twenty-nine loads of stone costing $72, sixteen loads of sand at a total cost of $35, and 160 bags of cement at a total cost of $64. The total cost of the material for the curb foundation amounted to $171.

Recording Cost of Street Sprinkling.—No record of the cost of street sprinkling is entirely satisfactory unless it shows:

1. The average daily wage of team and driver on the sprinkling wagon.

2. Number of miles of street of given width kept sprinkled each day by each sprinkling wagon.

3. Number of gallons of water averaged per day per square yard of street, of given kind of pavement, during the sprinkling season (usually Apr. 1 to Oct. 31 in the North).

4. Number of days that sprinkling was done during the year.

5. Cost per sq. yd. for the year for (a) water and (b) team time sprinkling it.

Contracts have often been let on the basis of a given price per 1,000 sq. yds. for sprinkling during the dry season. This form of contract is objectionable in that disputes are very apt to arise over the inspection of the work. What seems sufficient sprinkling to the contractor may seem quite insufficient to the inspector. I am strongly in favor of doing all sprinkling by contract, but the contract should be based, not upon the number of square yards sprinkled a stated number of times daily for a stated number of days, but upon *the number of gallons sprinkled from a nozzle of specified kind.* This involves metering the sources of water supply, which, however, is an expense of slight consequence.

The cost of sprinkling depends primarily upon the amount of water loaded into the tank, hauled and spread upon the street; hence the gallon is the proper unit of cost. Obviously, however, the kind of sprinkler or nozzle from which the water flows should be specified, so that too much water will not be put upon the street at one time and place.

Such a contract is flexible as to the number of sprinklings—depending on the weather—and is exact as to its payment in proportion to work done. Nor can it fail to be far cheaper, in the long run, than any attempt to do the sprinkling by day labor forces working for the city.

Cost of Street Sprinkling, Washington, D. C.*—About 40 miles of streets and roads in the District of Columbia are sprinkled each day upon which weather conditions were such as to render it necessary. The District owns its own sprinklers and teams and hires the drivers. In all 19 sprinklers are used, four on the heavily traveled

**Engineering-Contracting,* Dec. 4, 1907.

car-track paved streets, and 15 on macadam and dirt streets or roads.

Each sprinkler is required to cover two miles of territory from 8 a. m. to 5 p. m., at least three times each day. The sprinklers are 2-horse wagons, and have a capacity of 450 gallons each. On the average, it is necessary to fill the tanks about every 3½ squares, or a distance in one direction of 1,750 ft.

The dimension of the spray nozzle on the inside is 4½ ins. in diameter, and the holes through which the water flows vary from 2/32 ins. to 4/32 ins. and cover a diameter of 2½ ins.

The water is supplied free of charge, and drivers are paid $1.75 per day, in addition to which it is estimated that the cost of maintaining the 2 horses, repairs, etc., is about $1.25 per day, or a total of $3.00 for each day per wagon for each day upon which work is performed.

The cost of the sprinkling for the fiscal year ending June 30, 1907, was as follows:

Drivers	$ 4,621.27
Forage, pro rata	4,863.77
Horseshoes and nails, pro rata	218.55
Incidental expenses, pro rata	419.13
Miscellaneous expenses, pro rata	830.46
Wages of extra laborers	1,289.13
Total, 40 miles, at $306	$12,242.31

The total number of days worked was 195.

The cost of maintaining and operating each sprinkler for the fiscal year was about $644, or $3.30 per sprinkler per day worked. Since each sprinkler covered 2 miles of street, or about 37,500 sq. yds. daily, the total cost of sprinkling (exclusive of the cost of the water) was $644 ÷ 37,500 sq. yds. = 1.72 cts. per sq. yd. per season (of 195 days), for sprinkling three times daily.

Cost of Sprinkling Streets and Roads.—Mr. J. J. R. Croes says that to keep down the dust in Central Park, N. Y., from April 1 to Oct. 31 (7 mos.), about 100 cu. ft. (750 gals.) of water were used daily per 1,000 sq. yds. of macadam, the greatest amount on any one day being 157 cu. ft. per 1,000 sq. yds. Carts holding 41 cu. ft. of water were used. From the above it appears that about 160 gals. of water were used per sq. yd. of macadam during the 7 mos.

Mr. E. P. North states that to keep down the dust on an earth road, water applied twice daily, there were 143 cu. ft. (1,070 gals.) of water used daily per 1,000 sq. yds. A sprinkling cart holding 60 cu. ft. covered 850 sq. yds., or about ½ gal. per sq. yd.

Mr. E. W. Howe gives the cost of sprinkling park (macadam) roads. The road was sprinkled 10 times daily to keep the dust down, a sprinkler with fine holes being used.

	Per mile per year.
1,170,000 gals. water, at 16 cts. per 1,000 gals.	$187
Teams	533
Total	$720

Unfortunately the width of these park roads is not given, so that it is impossible to arrive at the amount of water or cost per sq. yd.

Amount of Water for Sprinkling Streets, Indianapolis and Minneapolis.—Mr. F. A. W. Davis gives the following. In Indianapolis, during the year of 1892, from Apr. 1 to Oct. 31 (7 mos.), 14,900,000 sq. ft. of streets were sprinkled, using 7.1 gals. per sq. ft., or 64 gals. per sq. yd., for the season. The water was metered and paid for at 8 cts. per 1,000 gals. (or $80 per 1,000,000 gals.). Hence the water cost $0.005, or ½ ct. per sq. yd., or about ½ mill per sq. ft. The sprinkling was done by contract, the prices ranging from $38 to $48 per 10,000 sq. ft., which is equivalent to 3.4 ct. to 4.3 ct. per sq. yd., for the season. The streets were sprinkled 3 to 4 times daily. Hence these contract prices were high.

During 1893 there were 8 gals. used per sq. ft., or 72 gals. per sq. yd.

It is stated that in Minneapolis, during 1893, each team on a sprinkling cart averaged 7,100 lin. ft. of street sprinkled per day, which is nearly 1.4 miles of street, there being 150 carts employed in sprinkling 207 miles of street. During two of the driest months of summer, 10,000,000 gals. were used per day, which is nearly 50,000 gals. per mile per day. The width of streets is not stated, but if they averaged 32 ft., there were 2.67 gals. of water per sq. yd. per day, during the two driest months.

Sprinkling Car Tracks.—The cost of sprinkling the street car tracks of the Detroit United Railway of Detroit, Mich., amounts to $4,123 per season; the company has eight sprinkling cars in operation, the cost for each car per year thus being $511. Two of the cars have tanks of a capacity of 3,670 gallons each, and six cars have a tank capacity of 3,702 gallons each. A car having a tank capacity of 3,702 gallons sprinkles at one filling 3.3 miles of track to a width of 8 ft. The rate per hour is 10½ miles.

Recording Cost of Street Sweeping.—Very rarely does an annual report on municipal street sweeping contain the data in form that admits of comparison with other cities. Sweeping cost data should be so compiled as to show the following:

1. The organization of the workmen, the numbers in each class, and their respective daily wages.

2. The average daily wage.

3. The number of days worked by the average workman during the fiscal year.

4. If possible, the average number of times all streets were swept during the year.

5. The cost of this sweeping per sq. yd. of street per year.

6. The cost per 1,000 sq. yds. for one sweeping.

7. The number of loads and cu. yds. of sweepings removed.

It is further desirable, where there are several different kinds of pavements, to give the unit costs of sweeping each class.

Where machines are used, their kind and number, as well as the methods of doing the work should be stated.

A common cost of sweeping is about 20 cts. per 1,000 sq. yds. swept once. Hence if a street is swept 3 times a week, or 156 times a year, the cost is 3.12 cts. per sq. yd. per year for sweeping.

It is commonly believed that street cleaning can not be well done by contract, due to the difficulty of specifying exactly what is wanted and of determining by inspection whether the contract is being lived up to. This is undoubtedly true where the attempt is made to contract at a given price per sq. yd. of street per year. On the other hand, it has been demonstrated in Washington, D. C., and elsewhere, that much of the difficulty vanishes when a contract is made on the basis of 1,000 sq. yds. swept once. Then, if, say, 3 sweepings a week does not give satisfactory cleanliness, the number of sweepings can be increased and paid for at the contract price of, say, 20 cts. per 1,000 sq. yds. swept once.

Under such a contract, the contractor should be required to work his men in fairly large gangs, and under the general direction of the city's representative. Under the "patrol system" of sweeping, each street cleaner is assigned a certain length of street to keep clean. This is a fairly satisfactory method where work is done by day labor by the city; but it is not an economic method, nor one to be generally used. The German method of having men work in large gangs is far more economic. It possesses the very important advantage of enabling one to know exactly how many times each street has been actually swept over each week, and thus makes it possible to determine what it has cost per 1,000 sq. yds. for each sweeping. As this is the only unit of cost of sweeping that admits of a rational comparison of the cost in different cities, or of the cost in different sections of the same city, it is obviously of the utmost importance to adopt the "gang system" and abandon the "patrol system" of sweeping.

Cost of Street Sweeping in 35 Cities.—In January, 1900, Mr. Andrew Rosewater, City Engineer of Omaha, Neb., collected the data shown in Table XIX. It will be noted that he secured the actual costs for the year 1898; and that the costs for 1899 were estimated, but probably close to actual. It is unfortunate that the data were not secured to show how many times the average street was swept in each city, for then we could have determined what it cost per 1,000 sq. yds. swept once.

Excluding New York, Chicago, Philadelphia and Pittsburg, the 31 remaining cities have 3,670 miles of paved streets with an area of 71,439,091 sq. yds. Hence the average width of pavement is 33⅓ ft., which is equivalent to 3.7 sq. yds. per lin. ft. of street, or 19,500 sq. yds. per mile. The estimated cost of cleaning these 31 cities in 1899 was $2,305,895 (including Newark and Minneapolis on the basis of 1898). This is equivalent to 3.23 cts. per sq. yd. of pavement for the year, or $32.30 per 1,000 sq. yds.

Assuming that the pavements of Chicago, Philadelphia and Pitts-

burg also averaged 33¼ ft. wide, the cost of cleaning the four large cities was:

	Per sq yd. Cts.
New York	18.0
Chicago	2.8
Philadelphia	3.1
Pittsburg	3.8

The shameful record of New York is well seen by this contrast.

There has been no improvement in New York since 1899. In fact the unit costs of cleaning have risen. In 1906 the boroughs of Manhattan and the Bronx, had 635 miles of paved streets, 12,366,000 sq. yds. and a population of 2,516,502. The cost of street sweeping alone was $1,566,482, or 12.7 cts. per sq. yd. The cost of carting all the refuse, ashes, garbage, and street sweepings, was $1,211,899. This material was carried away in scows and deposited in dumps at a cost of $775,249, making a total of nearly $2,000,000, of which at least 17% should be charged against the street sweepings, or $340,000, as that was their relative number of cart loads. This is equivalent to 2.8 cts. per sq. yd. of pavement. Administration expenses added 6%, or another 1.0 ct. per sq. yd., making a total of 16.5 cts., without any allowance for interest and depreciation on the plant (horses, carts, etc.), or for rents and miscellanies, which were fully 2 cts. more per sq. yd. The city accounts are so kept that complete unit costs are almost impossible to secure from the annual reports. Political misrule is written all over these New York City cost records.

Cost of Street Cleaning, Washington, D. C.*—The street cleaning work of Washington covers an area of 7,686,936 sq. yds. Of this amount 1,745,452 sq. yds. of paved streets are cleaned by hand patrol work; 3,245,297 sq. yds. of paved streets are cleaned by machine sweeping; 1,734,400 sq. yds. are unpaved streets; and 961,737 sq. yds. are public alleys, paved and unpaved.

The hand patrol work is done by municipal forces, a summary of the work done by them during the fiscal year ending June 30, 1907, being as follows:

Number of days worked	281
Number of men employed	189 to 215
Area cleaned, sq. yds	497,811,216
Area cleaned, miles	22,330
Debris removed, cu. yds	39,952
Bags of paper removed	56,292

From this it is evident that since 1,745,452 sq. yds. of street involved sweeping an area of 497,811,216 sq. yds., these streets must have been swept 285 times during the year, or not quite once every day.

The cost of the work was as follows for each sweeping:

	Total.	Per 1,000 sq. yds.
Labor	$82,336.91	$0.165
Materials, etc.	8,338.14	.017
Total	$90,675.05	$0.182

*Engineering-Contracting, Nov. 27, 1907.

TABLE XIX.—STREET CLEANING IN 35 AMERICAN CITIES.

Cities.	Population.	Sq. yds. of paving.	Paved streets, miles.	Cost of cleaning paved streets.† Actual 1898.	Cost of cleaning paved streets.† Estimated 1899.	Per 1,000 sq. yds.	‡Wages Men.	‡Wages Teams.	Remarks.
New York, N. Y.	3,550,000	30,423,800	1,396	$4,258,707	$5,476,088	$179.99	$722[5]	$3.50	E
Chicago, Ill.	1,351,000	....	1,248	675,000	....	.....	.....	.....	..
Philadelphia, Pa.	1,250,000	....	850	545,451	510,722	.....	.....	.....	C
St. Louis, Mo.	630,000	3,783,428	422	220,856	245,000	64.75	1.50	3.75	C
Baltimore, Md.	600,000	11,750,755	388	380,928	375,286	31.93	1.66⅔	3.25	D
Boston, Mass.	500,000	8,981,828	479	315,064	320,000	35.62	2.00	4.12	D
Buffalo, N. Y.	400,000	6,247,401	330	137,976	150,000	24.01	1.50	4.00	C
Cleveland, O.	400,000	3,422,222	170	650,000	55,000	16.07	1.30	3.50	C
Detroit, Mich.	347,000	4,940,000	268	130,000	144,500	29.25	1.50	3.50	D
Pittsburg, Pa.	300,000	....	219	137,821	163,499	.....	1.50	....	D
Washington, D. C.	287,000	4,623,076	206	177,000	145,000	31.36	1.75	3.50	C
Milwaukee, Wis.	280,000	1,760,000	75	98,223	103,371	58.73	1.50	3.50	C
Newark, N. J.	250,000	2,155,700	102	37,511	....	17.40	.17	.48⅛	C
Minneapolis, Minn.	255,000	1,574,649	99	41,681	....	26.47	1.75	3.00	D
Jersey City, N. J.	210,000	1,793,333	100	28,000	33,000	18.40	1.35	....	C
Indianapolis, Ind.	200,000	1,786,629	82	52,657	46,500	29.52	1.40	3.00	C
St. Paul, Minn.	175,000	1,000,000	45	30,000	34,000	34.00	1.50	3.00	D
Kansas City, Mo.	175,000	3,000,000	170	31,090	35,000	11.67	1.75	3.00	D
Denver, Colo.	165,000	530,000	19	25,000	27,800	52.45	2.00	3.00	D
Omaha, Neb.	150,000	1,954,416	83	23,142	18,716*	9.57	1.50	3.00	D

Toledo, O.	150,000	1,896,292	125	9,468	10,024	5.28	1.50	3.00	C
Syracuse, N. Y.	125,000	793,000	36	40,776	72,485	9.14	1.50	3.50	D
Allegheny, Pa.	125,000	1,500,000	83	29,267	35,000	23.33	1.50	....	D
Columbus, O.........	121,000	2,160,468	116	27,923	64,000	29.62	1.50	3.00	C
Los Angeles, Cal.....	115,000	530,000	18	......	27,953	52.74	2.00	3.50	C
Worcester, Mass.	114,000	237,454	11	11,000	11,444	48.19	1.75	4.00	D
Richmond, Va.	100,000	350,000	22	48,151	56,500	161.43	1.50	....	D
Albany, N. Y........	100,000	1,419,545	81	41,000	41,000	28.88	1.50	2.00	D
Lowell, Mass.	89,000	336,500	17	20,384	20,384	60.58	1.75	2.00	D
Dayton, O.	85,000	709,820	29	31,065	30,000	42.26	1.50	3.50	D
St. Joseph, Mo.......	75,000	950,000	45	9,000	9,000	9.41	1.50	2.75	D
Lynn, Mass.	70,000	75,000	3	5,300	6,300	84.00	2.00	....	D
Trenton, N. J........	66,000	381,271	18	9,000	9,000	23.57	1.50	4.00	D
Evansville, Ind.	65,000	688,533	25	75,000	95,000	137.97	....	....	C
Salt Lake City, Utah.	60,000	107,771	3	3,909	5,440	50.47	1.75	3.00	E

*Includes $2,000 for removal of snow and ice. †Assuming that all paved streets in each city are cleaned. §Per annum.

‡Cleveland reported that 9 hours constituted a day's work; 8 hours was reported for Buffalo, Detroit, Pittsburg, Omaha, Allegheny, Los Angeles, Albany, and St. Joseph; the other places did not report.

Note.—The letters in the Remarks Column indicate the following: C, sweeping and sprinkling at the time of sweeping done by contract; D, sweeping and sprinkling at the time of sweeping done by day labor; E, sweeping done by contract but sprinkling at the time of sweeping done by day labor. All cities, except Dayton and Trenton, reported that machines were used in sweeping.

The item materials, etc., included the following:

Bamboo, bass and blocks	$1,268.47
Bags	1,920.00
Corn brooms	108.00
Horse shoes and nails, pro rata	141.85
Forage, pro rata	3,157.18
Incidental expenses, pro rata	279.12
Miscellaneous	1,415.52
Rent of tool house	48.00
Total	$8,338.14

The cost of hand cleaning per cubic yard of debris removed, exclusive of waste paper, was $2.269, as against $2.091 in 1906, the increase being due to the longer haul.

The average width of the streets cleaned was 38 ft., and the cost per mile of cleaning was $4.06. A total area of 1,745,452 sq. yds. was gone over each day. The wage paid laborers was $1.50 per 8-hr. day, and each laborer had an average street service area of between 9,000 and 10,000 sq. yds.

The cost of this hand sweeping was 5.2 cts. per sq. yd. of pavement per year, which is just twice what the machine sweeping cost, due principally to the fact that the machine swept streets were only swept 115 times during the year.

A total of 56,292 large sacks of paper was gathered in the hand cleaning district alone, an average of 200.3 sacks per working day. Only a small proportion of this amount was taken from the waste paper boxes placed at different points throughout the business district. In order to keep the streets and sidewalks within the hand cleaning territory free of paper during the daytime an average of two hours out of the eight was devoted by the laborers to picking it up. For this purpose the men were required to go over their respective sections four times per day—the first thing in the morning, before lunch, after lunch, and toward the end of the working day.

The machine sweeping of paved streets (3,245,297 sq. yds.) was done by contract, a summary of the work accomplished for the fiscal year 1907 being as follows:

Number of days worked	241¼
Area cleaned, sq. yds.	373,029,844
Area cleaned, miles	16,733
Debris removed, cu. yds.	86,814
Contract price per 1,000 sq. yds. per sweeping	$0.22¾
Cost per mile per sweeping	$5.07

The area covered by machine sweeping was as follows:

Area, sq. yds.	3,245,297
Cost per sq. yd. per year	2.62 cts.
Area, miles	145.6
Average width of paved street, ft.	38
Area cleaned per day, sq. yds.	1,991,465
Area cleaned 6 times per week, sq. yds.	737,633
Area cleaned 3 times per week, sq. yds.	1,253,832
Average number of times streets were swept	115

A summary of the work of cleaning the unimproved streets

(1,734,440 sq. yds.), consisting of rough cobblestone, macadamized, gravel and dirt roads and streets is as follows:

Number of days worked	276
Area cleaned, sq. yds.	31,007,419
Area cleaned, miles	1,652
Debris removed, cu. yds.	20,235
Contract price per day for full force	$73.80
Cost per 1,000 sq. yds. per sweeping	$0.586
Cost per mile per sweeping	$11
Average number of times streets were swept	18

The total area of unpaved streets was 1,734,440 sq. yds., the average width being 32 ft. A total area of 214,195 sq. yds. was cleaned each day.

The cleaning of public alleys (961,737 sq. yds. paved and unpaved) was done by contract, a summary of the work done being as follows:

Number of days worked	250
Area cleaned, sq. yds.	44,131,505
Area cleaned, miles	6,269
Average width of alleys, ft.	12
Debris removed, cu. yds.	12,286
Contract price per 1,000 yds. per sweeping	$0.40
Cost per mile per sweeping	$2.816
Average number of times swept	46

Cost of Sweeping Streets Washington, D. C.—Mr. Warner Stutler gives the following:

During the year, July 1, 1901-02, 1,565,809 sq. yds. asphalt were swept daily by hand. There were 200 men, at $1.25, and 9 teams. The total area cleaned was 413,765,028 sq. yds., at a cost of 18.6 cts. per 1,000 sq. yds. for each sweeping.

The number of times swept during the year was 413,765,028 ÷ 1,565,809 = 264. Hence the cost per sq. yd. of pavement per year, for sweeping, was 4.9 cts.

Then a "pick-up" sweeper ("The Peerless," made by Barron & Cole, of New York City) was adopted, with which a laborer could clean 33% more area daily than with hand brooms and do better work.

Cost of Sweeping With a "Pickup" Sweeper.*—During the summer of 1907 Mayor Geo. B. McClellan appointed Mr. H. de B. Parsons, Dr. Rudolph Hering and Mr. Samuel Whinery a commission to report on an improved and more effective system of street cleaning and waste disposal than is now in operation in New York City. At the end of the year this commission made its report, which has since been printed by the city.

The report covers nearly 250 pages, and has in it much valuable information on street cleaning and waste disposal. The commission has made a study of many features of this kind of work, and has collected a large amount of data on the subject.

The report discusses at some length the various methods used

***Engineering-Contracting*, May 6, 1908.

in street cleaning, and gives an estimated cost for each method described, thus allowing a comparison of each with the other. The estimate on hand sweeping by the "patrol method" is as follows: Cost of one outfit:

One hand cart		$10.00
Five cans for sweepings, at $2.50		12.50
Four hand brooms, at 65 cts		2.60
One shovel		0.75
Two steel scrapers, at $2		4.00
Total		$29.85
Annual charges:		
Interest on outfit at 4%	$ 1.19	
Repairs and depreciation at 60%	17.01	
Total annual charges	$19.10	
Or for 310 days, per day		$0.062
Cost of operation per day, 1 man sweeping		2.190
Total cost per day		$2.252

On the basis that one sweeper will clean satisfactorily 8,000 sq. yds. of pavement per day the cost per 1,000 sq. yds. will be 28.1 cts.

In closing their remarks on hand sweeping the commissioners said:

"A modified method of hand sweeping in use in a number of American and foreign cities consists in substituting for the ordinary push broom a small machine with a revolving broom. This machine is generally similar to the large machine sweeper, except that it is designed to pick up its own sweepings and deposit them in an attached receptacle, which is emptied when necessary. This small machine is pushed over the street by the street sweeper and does its work quite well when the street is dry. It is extensively used in Washington, where it is well liked. One objection is that on heavy traveled streets there is difficulty in working it among horses and vehicles. Upon the whole, this hand sweeping machine is not in general favor in American cities."

It is to be very much regretted that this commission of eminent engineers did not make a thorough investigation of this sweeping machine and report their findings on it. This type of machine seems to us to solve some of the problems of street cleaning, and in this article we give some data that we have collected. We realize that their can be some objection to any method, but on good pavements these machines can effect a saving over the patrol hand sweeping, and at the same time do much more efficient work.

This style of machine has been used in Washington, D. C., since the summer of 1901, and, as the commission states, "it is well liked." The name of the machine used in Washington is the "Peerless," sold by Barron & Cole, of New York City.

Prior to the installation of these machines in Washington a patrol sweeper swept daily 7,456 sq. yds., and with the pick-up machine the same man covered 9,145 sq. yds., an increased area of more than 22 per cent. In order to compare this with the costs given above the same wages will be applied. Thus we have:

Cost of one outfit:

One Peerless hand sweeper		$75.00
Forty bags		4.00
Four upright brooms at 35 cts		1.40
One shovel		.75
One steel loosener		.40
Total		$81.55
Annual charges:		
Int. on outfit at 4%	$ 3.26	
Four new brooms at $4	16.00	
Depreciation at 20%	16.31	
Total annual charges	$35.57	
Or, for 310 days, per day		$0.114
One man		2.190
Total cost per day		$2.304

With the area of 9,145 sq. yds. swept per day this gives a cost per 1,000 sq. yds. of 25.1 cts., or just 8 cts. less than the estimated cost of the patrol sweeping.

The working day in Washington, like New York, is 8 hrs., but the machines are only operated 6 hrs. each day, as the men spend 2 hrs. each day in picking up paper. For this purpose the men are required to go over their respective sections four times per day—the first thing in the morning, before lunch, after lunch, and towards the end of the working day. It would seem possible that this paper could be cared for in some other way. With ordinances properly enforced the greater part of it should be put into boxes on the sidewalks by the users of the street, thus preventing the paper from being scattered in the street. With the waste paper eliminated and the men employed on the machines operating them 8 hrs., the area covered per day would be between 11,000 and 12,000 sq. yds. at a cost of about 20 cts. per 1,000 sq. yds. The style of box for depositing waste paper should be somewhat similar to the package mail boxes used by the government, as the self-closing lids prevent the paper from being blown out of the boxes by the wind.

Burlap bags should likewise be used for collecting the street sweepings, instead of cans. The bags are cheaper and better adapted to the work. The dirt receptacle on a sweeper ordinarily holds the sweepings of about 800 sq. yds. When the dirt is dumped from the sweeper it can be shoveled into a bag, the bag being held open on hooks made for the purpose on the handle of the machine. The bag can be tied up and placed on the sidewalk for the pick-up wagon to carry away. With a bag it is not possible, either, for the wind or some boy to scatter the dirt as with an open top can. With the machine carrying a bag on the hooks on the handle paper can also be picked up by the operator as he passes a piece and placed in the bag. With bags a larger load, without chance of spilling any dirt, can be carried on the pick-up wagon or cart.

Upright brooms are cheaper than push brooms, and can be used with this machine, as brooms are only needed to sweep the dirt away from curbs or in taking up the sweepings after the machines have been emptied.

The steel loosener has a long handle and is used to loosen any

materials that have become stuck to the pavement, the length of the handle admitting of this being done without the operator leaving his position behind the machine.

The machine uses up four brooms a year, and these have been charged in the annual expenses. The life of a machine is from 8 to 10 years, hence a depreciation of 20 per cent per year is more than ample to allow, and this will also cover renewals, as we are informed by the manufacturer that for about 200 machines used by the city of Washington the repair parts ordered during the past two years have not amounted to quite $200, or a yearly expense of less than 50 cts. for each machine.

The great problem in street cleaning is the removing of the finer particles and the dust. The commission, in its report, dwells at some length on this. The coarser particles, they state, are easily cleaned up, but even when a street has been swept there still remains the dust, which is a "serious menace to health and a destructive and discomforting element of city life." The hand pick-up sweeper does not take up all of this dust, but it does take up the greater part of it, as is evident when one walks along Pennsylvania Ave. in Washington on a windy day, for it is possible to keep one's eyes open without having them filled with dust. In New York a puff of wind means a cloud of dust. On this point the superintendent of the street cleaning department of Washington, in his report dated June 30, 1902, in commenting on the work of these machines, said:

"The daily area cleaned, therefore, was not only enlarged and the expenses reduced, but the streets were kept cleaner than ever before."

Estimated Cost of Machine Sweeping.—In the Parsons-Hering-Whinery report, above mentioned, the cost of sweeping with horse-drawn machines (having revolving brooms) is estimated as follows:

Cost of one outfit:	
1 sweeping machine	$ 275.00
½ of 1 one-horse sprinkling cart	104.00
12 hand brooms at $0.65	7.80
6 shovels at $0.75	4.50
2 horses for sweeper	600.00
½ horse for ½ sprinkler	150.00
2½ sets of harness at $25	62.50
Total outfit	$1,203.80
Annual plant charges:	
Interest on $1,203.80 at 4%	$ 48.15
Repairs and depreciation on tools, at 20%	90.76
Depreciation on horses, at 15%	112.50
Total, 310 days at $0.81	$ 251.41
Operating expenses:	Per day.
Maintenance of 2½ horses at $1.35	$ 3.38
Rent, storage of sweeper	0.20
Wages, 1 sweeper driver	2.19
Wages, ½ sprinkler driver	1.09
Wages, 6 gutter sweepers, at $2.19	13.14
Plant charges	0.81
15,000 gals. water at $90 per million	1.35
Total, 70,000 sq. yds. at 31.7 cts. per 1,000 sq. yds.	$ 22.16

This is estimated for an 8-hr. day in New York City, and for an asphalt pavement. It does not include loading the sweepings into carts and carting away.

Estimated Cost of Flushing Streets.—In the Parsons-Hering-Whinery report, above mentioned, the cost of flushing New York streets with a horse and with a machine are estimated as follows:

Using a 2½-in. fire hose with a 1¼-in. nozzle, under a pressure of 40 lbs. per sq. in., 235 gals. per min. are discharged, and 4,000 to 10,000 sq. yds. are washed per hour. Assuming an average of 6,000 sq. yds. per hr., and that the water jet is operating 80% of the time, there would be 1.88 gals. used per sq. yd.

The cost of one outfit is:	
100 ft. of 2½-in. hose at $1.10	$110.00
1 fire nozzle	12.50
6 brooms	3.90
	$126.40
Annual plant charges:	
Interest on $126.40 at 4%	$ 5.06
Repairs and depreciation 150%	189.60
Total, 310 days at $0.63	$194.66
Operating expense:	Per day.
3 men at $2.19	$ 6.57
90,000 gals. water at $90 per million	8.10
Plant charges	0.63
Total, 48,000 sq. yds. at 31.9 cts. per M	$15.30

It was estimated that as rapid and as thorough work could probably be secured with a 1-in. special nozzle (on a 2-in. hose), throwing a fan-shaped jet, and with 30 lbs. per sq. in. pressure. Under such conditions, the cost of flushing was estimated thus:

	Per day.
2 men at $2.19	$ 4.38
57,600 gals. of water at $90 per million	5.18
Plant charges	0.48
Total, 40,000 sq. yds. at 25.1 cts. per M	$10.04

Street flushing with special wagons was estimated as follows. The wagon has a tank with two airtight compartments, one holding water (600 gals.) and the other holding compressed air, the two being connected above the water line. When the water tank is filled with a hose, air is compressed in the air compartment. In flushing the water is forced out at a pressure of about 35 lbs. per sq. in. through a special nozzle.

Cost of one outfit:	
One flushing wagon	$1,000.00
6 hand brooms at $0.65	3.90
3 shovels at $0.75	2.25
2 horses at $300	600.00
2 sets harness at $25	50.00
Total	$1,656.15
Annual plant charges:	
Interest on $1,656.15 at 4%	$ 66.25
Repairs and depreciation on tools at 14%	147.86
Depreciation on horses at 15%	90.00
Total, 310 days at $0.98	$ 304.11

Operating expenses:	Per day.
1 driver	$ 2.19
½ day helper	1.09
Maintenance 2 horses at $1.35	2.70
4 men collecting dirt in gutters at $2.00	8.00
Rent, storage of plant	0.20
Plant charges	0.98
56,000 gals. water at $90 per million	5.04
Total 28,000 sq. yds. at 72.1 cts. per M.	$ 20.20

Cost of Street Sweeping, Minneapolis.*—The asphalt pavement of the city of Minneapolis, Minn., is swept by hand, using the Ross scraper according to the block system. Each man has from two to five blocks to keep clean. The sweepings are deposited in galvanized iron cans placed at street corners, from which they are removed by teams. The asphalt pavement is also swept by machine at night, and flushed whenever necessary.

The wages paid per day are as follows: Teams, $4; men, $1.50 to $2.

According to the annual report of the city engineer, the cost of hand sweeping for 1906, 21 men being employed, was $16,049, or 8.69 cts. per sq. yd. per year.

The cost of cleaning, machine sweeping and washing was $9,276, or 5.02 cts. per sq. yd. per year.

A total of 11.65 miles of 27-ft. roadway cost per mile per year for cleaning, $796; for sweeping, $1,378, or a total of $2,174.

In all 184,528 sq. yds. of asphalt pavement were cleaned and swept.

The cost of cleaning and sweeping the other paved (not asphalt) streets was $43,014, or 3.33 cts. per sq. yd. This cost is for a yardage of 1,290,930 sq. yds., and does not include macadam and asphalt pavement. The cost of cleaning was 1.47 cts. per sq. yd., and the cost of sweeping was 1.86 cts. per sq. yd.

During 1899 there were 200,000 sq. yds. of asphalt pavement cleaned by hand by the block system. The sweepings were put into cans, from which they were collected by teams. The gang was 31 men at $1.75 and 5 teams at $3.50. The cost was:

	Per sq. yd. Per year. Cts.
Machine sweeping and washing	1.45
Hand sweeping	5.74
Total	7.19

Cost of Street Sweeping, Williamsport, Pa.†—Mr. James F. Fisher, City Engineer of Williamsport, Pa., in his report for 1907, gives the cost of sweeping the streets by machines.

The work is done by employes of city engineer's department, the force used and the wages paid being as follows:

**Engineering-Contracting*, Jan. 29, 1908.

†*Engineering-Contracting*, May 6, 1908.

One team on sprinkler	$ 4.50
One team on sweeper	4.50
Two one horse pick up wagons	5.50
Four men 10 hrs. at $1.65	6.60
Total for one day	$21.10
Int. and depreciation of outfit	1.00
	$22.10

The one dollar added covers interest at 6% per annum and depreciation of the plant at 20% per year, divided by 200 working days, which is the length of the season in Williamsport.

Each day this force sweeps parts of seven streets aggregating 62,000 sq. yds. This gives a cost per 1,000 sq. yds. for cleaning by machine sweeping of 35.6 cts. The city has 206,875 sq. yds. of improved pavements, which would cost $73.65 to clean daily, or $14,730 for a season of 200 working days, which is equivalent to 7.1 cts. per sq. yd. per year. This enormously high cost shows the usual low efficiency of men working by the day for a city.

Cost of Sweeping, Rochester, N. Y.—Mr. Edwin A. Fisher gives the following cost of sweeping for Rochester, N. Y., in 1901:

	No. times swept.	Per sq. yd. for year.
Asphalt streets	99	3.71 cts.
Brick	60	2.69 cts.
Medina stone block	101	5.27 cts.

It will be noted that, at this rate, each sweeping cost:

	Per 1,000 sq. yds.
Asphalt streets	37 cts.
Brick	47 cts.
Medina stone block	52 cts.

These high costs show poor efficiency of workmen.

These streets were sprinkled at a cost of 2.21 cts. per sq. yd., or $350 per mile, during the year.

Cost of Street Sweeping, Albany, N. Y.*—The street cleaning of Albany, N. Y., is effected by three methods: Machine sweeping of improved streets; hand cleaning of cobblestone streets and alleys and hand cleaning in the business district. All of the work is done by city forces, and the city owns the sweeping machines and street sprinklers and hiring necessary teams and drivers.

In the principal business districts the asphalt pavements (173,000 sq. yds.) are kept cleaned and waste paper picked up. The following regular gang is employed for this work, the wages being $1.75 per day:

2 men cleaning granite cross-walks	$ 3.50
3 men cleaning asphalt	5.25
2 men picking up waste paper	3.50
Total daily expense	$12.25

This is equivalent to an annual expense of $4,100, or nearly 2.4 cts. per sq. yd., not including the additional cost of sweeping streets with machines.

*_Engineering-Contracting_, Dec. 4, 1907.

The cobblestone pavements, of which there is a total area of 229,229 sq. yds., are cleaned by hand hoes or broom, at the following daily expense:

1 foreman, at $2.35	$ 2.35
10 men, at $1.75	17.50
1 horse and driver for sprinkler, at $3.50	3.50
Total	$24.35

The pavements are cleaned for a period of eight months at a total cost of about $4,800, or 2.1 cts. per sq. yd. per year.

The principal part of the street cleaning work is effected by machine sweeping, the areas and kinds of pavement covered being as follows:

	Sq. yds.
Granite block pavements	560,623
Vitrified brick pavement	458,733
Sheet asphalt	173,094
Asphalt block	14,500
Total	1,206,950

This area is swept twice a week during eight months of the year, or from about April 1 to December 1. The force engaged in machine sweeping consists of four gangs, each under a foreman, and made up of 1 street sprinkler, 2 machine sweepers and 12 men. Each gang has its regular district to cover day or night as the case may be.

The sweeping is done in the usual manner, the pavements first being lightly sprinkled with water to lay the dust and then swept with the machines, the dirt being pushed by the latter from the center of the street to each of the gutters. The men then sweep the dirt into piles along the gutters at intervals of about 25 ft. Machine cleaning in the business district is done only at night.

The daily labor cost of sweeping and collecting the dirt in piles is as follows:

8 teams and drivers for 8 sweeping machines, at $5	$ 40.00
4 teams and drivers for 4 sprinklers at $5	20.00
4 foremen, at $2.35	9.40
48 men, at $1.75	84.00
Total daily labor cost	$153.40

The above force is employed about eight months, the total yearly expense for labor being about $32,000. The cost of repairs to sweeping machines and sprinklers, cost of new brooms and refitting old brooms and other incidentals amounts to about $4,000 per year, making a total cost of sweeping the dirt into piles amount to about $36,000. As the total amount of pavement swept over each amounts to about 85,000,000 sq. yds., the cost of sweeping the dirt into piles is about 42 cts. per 1,000 sq. yds. for each sweeping. This does not include the cost of shoveling the dirt from the piles into wagons and conveying it to dumps or other places where it is used for filling. This work is done by contract, the price for 1907 being $11,500.

There are 8 public dumps, which receive street dirt, ashes, etc.,

and are cared for by 9 men at an expense of $15.75 per day, or about $5,000 per year.

Since the 1,206,950 sq. yds. involve 85,000,000 sq. yds. of sweeping yearly, each street is swept about 70 times during the year.

Summing up we have the following cost of sweeping 1,206,950 sq. yds., not including the 229,229 sq. yds. of cobblestone pavement:

	Per year.	Per sq. yd. per year Cts.
Laborers cleaning business streets	$ 4,100	0.34
Gangs with street sweeping machines	32,000	2.65
Repairs to sweeping machines, etc.	4,000	0.33
Loading and hauling dirt to dumps (by contract)	11,500	0.95
Spreading dirt and ashes at dumps	5,000	0.42
Total	$56,600	4.69

It should be remembered that the first item, "laborers cleaning business streets," costs 2.4 cts. per sq. yd. of business street cleaned, which becomes 0.34 ct. per sq. yd. of entire area of city streets.

Since the 8 machine sweepers sweep 85,000,000 sq. yds. in the working season (8 mos.), each machine covers 10,600,000 sq. yds. in the 210 working days, or 50,000 sq. yds. per day, at a cost of 38.4 cts. per 1,000 sq. yds. swept once. This is for labor alone, and, as will be seen from the tabulation of wages above given, more than 50% of this cost is for the wages of the laborers who sweep the dirt into piles in the gutters ready to haul away, there being 6 such men to each machine sweeper. This is an exceedingly high cost, but it does not include the excessive cost of repairs, etc., which is $500 per year for each machine sweeper (plus half a sprinkler), etc., or nearly $2.50 per working day, thus adding nearly 5 cts. per 1,000 sq. yds. swept.

Summing up we have the following total cost for sweeping 1,000 sq. yds. each time:

	Per 1,000 sq. yds. Cts.
Gang with street sweeper	36.4
Repairs to sweeper, etc.	4.7
Loading and hauling dirt (by contract)	13.6
Spreading dirt and ashes	6.0
Total	60.7

All of the last item is not properly chargeable to sweeping, since it involves spreading ashes also.

In excuse for these exceedingly high costs it has been said that a large part of the pavement is granite blocks and that the Albany streets are in many cases very steep, or hilly. This excuse is inadequate, for not half the streets are granite, and far less than half are steep. The true excuse is the general inefficiency of men working by the day for any municipality.

Cost of Street Flushing and Sweeping, St. Louis, Mo.*—The street cleaning of St. Louis is done by the day labor plan, six day

*_Engineering-Contracting_, Jan. 15, 1908.

gangs and four night gangs being employed in the work. A gang comprises the following:

5 flushing machines at $6.00	$30.00
4 dirt wagons at $4.50	18.00
6 laborers at $1.50	9.00
1 inspector at $3.00	3.00
Total	$60.00

From 20 to 35 gals. of water are used for each square (100 sq. ft.) of flushing, or 2 to 3 gals. per sq. yd. The average cost to the city per great square (10,000 sq. ft.) for one flushing of the pavements in the business and residence districts is $1.10, or $1 per 1,000 sq. yds. This estimate is based upon the number of squares flushed per month, without regard to the paving material, or where the streets cleaned are located. It is possible to flush an asphalt pavement in the residential district for $0.75 per great square, or $0.70 per 1,000 sq. yds.; while the granite block pavements in the business district, where the delays are caused by traffic, may cost $1.35 per great square, or $1.22 per 1,000 sq. yds.

The average cost for machine broom sweeping is about $0.50 per great square, or $0.45 per 1,000 sq. yds., these machines being used on the brick pavements except where the streets are very dirty.

The block patrol system of cleaning is also employed. In this, one man is given about five city blocks to clean, the average length of block being 300 ft. With wages at $1.50 and the width of roadway assumed at 36 ft., 5½ great squares are cleaned each day at a cost of $0.28 per great square, or $0.25 per 1,000 sq. yds. The system of street sprinkling aids very much the cleaning of streets by the block system, as all of the paved streets are sprinkled from one to four times per day, the cost thereof being charged as a special tax against the property fronting the street sprinkled, the average rate for the year amounting to about $0.04 per front foot.

The total mileage of hard pavements is as follows:

	Miles.
Asphalt	45.42
Bituminous macadam	24.46
Vitrified brick	96.19
Granite blocks	63.48
Wood blocks	2.50
Total	232.05

In addition, 134 miles of improved alleys are cleaned from the appropriation for street cleaning.

It will be noted that all these costs are exceedingly high.

Life of Sweeping Machines.—In Berlin the life of horse-drawn sweeping machines (rotary brooms) has been about 20 years. A rotary broom lasts only 21 days when used every night; a machine requires 17 brooms yearly, and works 7 hrs. daily.

SECTION V.

STONE MASONRY.

Definitions.—Consult Section VI, on Concrete, for definitions not found in this section.

Abutment.—The foundation or substructure of a bridge. Abutments are built on the banks of a stream; piers are built in the stream itself.

Apron.—A covering over the earth or rock below the spillway of a dam.

Arch Culvert.—A culvert with an arched roof.

Arch Masonry.—That portion of the masonry in the arch ring only, or between the intrados and the extrados.

Ashlar.—First-class squared stone masonry dressed so that its joints do not much exceed ½-in. in thickness.

Axed.—Dressed so as to cover the surface of a stone with chisel marks which are nearly or quite parallel.

Back.—The rear face of a wall.

Backing.—The rough backing masonry of a wall faced with a higher class of masonry. The earth deposited back of a wall or arch is sometimes miscalled backing instead of backfilling or lining.

Barrel.—The under surface of an arch. See Soffit.

Bat.—A part of a brick or stone.

Batter.—The backward slope of the face of a wall. A 1-in. batter means that the face of the wall departs from a plumb line at the rate of 1 in. in every foot of rise.

Beds.—Or bed joints, the horizontal joints of masonry. See also "Natural bed."

Belt Course.—A projecting course of masonry immediately under the coping; a belt course is often called a corbel course. Its object is to give a better appearance to a wall.

Bench Wall.—The wall or abutment supporting an arch.

Blind Header.—A header that extends only a short distance back into a wall instead of extending to the full depth specified; blind headers are also called "bob-tails."

Block Rubble.—Large blocks of building stone as they come from the quarry. See Rubble.

Bond.—The arrangement of stones so as to overlap or "break joints."

Box Culvert.—A culvert having a waterway of rectangular cross-section.

Breast Wall.—A wall built against the face of an excavation to prevent its caving down; also called a face wall.

Bridge Seat.—See Pedestal.

Broken Range Masonry.—Masonry in which the bed joints are parallel but not continuous.

Build.—A vertical joint.

Bulkhead.—A head wall at the end of a culvert, and perpendicular to the axis of the culvert. See Head Wall.

Bush Hammer.—To dress stone with a hammer having a number of pyramidal cutting teeth on its striking face.

Buttress.—A vertical piece of masonry projecting from the face of a retaining wall to strengthen it.

Centers.—The temporary structure that supports an arch during its construction. (Also called Centering.)

Chisel Draft.—A narrow plane surface cut with a pitching chisel along the outer edges of the face of an ashlar stone, usually cut the width of the chisel.

Classes.—Different kinds of masonry specified, usually, first, second and third class; the first class being the most expensive. What is "first class" according to one engineer may be "second class" according to another.

Closer.—A narrow stone used to finish a course of masonry.

Coping.—The top course of stones on a wall, usually made of large flat stones which are laid so as to project a few inches over the face of the wall. A projecting coping relieves the wall of a "bobtailed" appearance.

Course.—A horizontal layer or tier of stones. "Coursed masonry" is built up in courses.

Course Bed.—Stone, brick or other building material in position, upon which other material is to be laid.

Cover-Stones.—The flat stones forming the roof of a box culvert.

Cramp.—A bar of metal having the two ends bent at right angles to the bar for insertion into holes drilled in adjoining blocks of stone.

Crandall.—A stone dressing hammer, consisting of a steel bar with a slot in one end holding 10 double-headed points of steel (¼-in. square x 9 ins. long), producing an effect like fine pointing.

Crown.—The top of an arch at its highest point.

Cull.—A rejected stone or brick.

Culvert.—A waterway under a road, canal or railroad embankment.

Cut-Stone.—A stone that is carefully "dressed" or shaped with tools.

Cut-Water.—The upper wedge-shaped end of a bridge pier.

Cyclopean Masonry.—Masonry made of huge stones, usually bedded in concrete.

Damp-Course.—A waterproofed course or bed joint in a wall, usually just above the surface of the ground; its purpose being to prevent the rise of water in the pores of the stone and mortar due to capillary action.

Depth.—The width of a stone measured perpendicularly to the face of the wall; the distance that a face stone extends into the wall.

Dimension Stone.—Stone dressed to exactly specified dimensions.

Dirt Wall.—See "Mud Wall."

Dog Holes.—Shallow holes drilled in a stone to afford a bite for the "dogs," or hooks, used in lifting the stone with a derrick.

Dowel.—A short steel pin inserted part way into the adjoining faces of two blocks of stone.

Draft Line.—See "Chisel Draft."

Drafted Stones.—Stones on which the face is surrounded by a draft, the space inside the draft being left rough.

Dress.—To cut or shape a stone with tools.

Drove.—Dressed on the face so as to have a series of small parallel ridges and valleys.

Dry Wall.—A stone wall built without mortar.

Efflorescence.—A white crust that often forms on the face of masonry, due to the leaching of soluble salts out of the mortar; often called "whitewash."

Expansion Joint.—A vertical joint or space to allow for temperature changes.

Extrados.—The curve that bounds the outer extremities of the joints between the arch stones, or voussoirs.

Face.—The front surface of a wall.

Face Stones.—The stones forming the front of a wall.

Face Wall.—See "Breast Wall."

Fine Pointed.—Dressed by fine point to smoother finish than by rough point.

Flush.—(Adj.) Having the surface even or level with an adjacent surface. (Verb.) (1) To fill. (2) To bring to a level. (3) To force water to the surface of mortar or concrete by compacting or ramming.

Footing Courses.—The bottom or foundation courses, which usually project beyond the "neat work" of an abutment.

Foundation.—(1) That portion of a structure, usually below the surface of the ground, which distributes the pressure upon its support. (2) Also applied to the natural support itself; rock, clay, etc.

Foundation Bed.—The surface on which a structure rests.

Frost Batter.—A batter occasionally given to the rear of a wall near its top to prevent the dislocation of the top course of stones upon the formation of frost in the ground.

Full-Centered.—An arch that is a full semi-circle, or half circle.

Groin.—The curved intersection of two arches meeting at an angle.

Grout.—A thin watery mortar which is poured into the joints after the stones have been laid.

Haunch.—The part of an arch between the crown and the skewback.

Header.—A stone laid with its longest dimension perpendicular to the face of the wall.

Head Wall.—An end wall, or bulkhead, of a culvert.

Hollow Quoin.—The vertical semi-circular groove in the masonry into which nts the "quoin post," or hinge post, of a canal lock gate.

Intrados.—The inner circle of an arch.

Joint.—The space between adjacent stones; sometimes the word joint is used to denote the vertical joints only, in distinction from the "beds" or bed joints. Joints are usually filled with mortar.

Keystone—The center stone at the crown of an arch.

Lagging.—The sheeting plank placed upon the ribs of arch centers.

Length.—The longest dimension of a stone.

Leveler.—A small rectangular stone, not less than 4 to 6 ins. thick, used in broken range work to complete the bed for a stone in the course above and give it proper bond. Sometimes called jumper or dutchman.

Lewis Hole.—A wedge-shaped hole in a block of stone, made for the purpose of lifting the block by the aid of a lewis.

Lining.—The gravel or broken stone filling back of a slope wall or retaining wall, for the purpose of drainage and to protect the earth from wash.

Lock.—Any special device or method of construction used to secure a bond in the work.

Mortar.—A mixture of sand with cement (or lime) and water. A 1 : 2 (one to two) mortar contains 1 part cement and 2 parts sand.

Mud-Wall.—A small parapet or retaining wall built on top of a bridge abutment to prevent the earth backfill from sliding or washing down upon the coping.

Natural Bed.—A laminated or stratified stone is laid in its "natural bed," or "quarry bed," when its laminations are horizontal or are perpendicular to the load that they carry. Granite has no "natural bed."

Neat Mortar.—Mortar made without sand.

Neat Work.—That part of an abutment above the footing courses, which is generally equivalent to saying, that part above the surface of the ground or water.

Nigged.—Hewed with a pick.

Niggerheads.—Rounded cobble stones.

Parapet.—The "mud-wall" of a bridge abutment; the "bulkhead" of a culvert; the spandrel wall at each end of an arch bridge or culvert, but more properly the extension of the spandrel wall above the crown of the arch; a low guard wall rising above the surface of a roadway or walk to prevent pedestrians or vehicles from leaving the roadway or walk.

Patent Hammer.—A double-faced hammer so formed as to hold at each face a set of wide thin chisels for giving a finish to a stone surface.

Paving.—Regularly placed stone or brick forming a floor.

Pedestals.—Or pedestal blocks, are stone blocks on top of an abutment coping; the pedestal blocks receive the weight of the bridge, and are often called "bridge seats"; the term pedestal is

also applied to a small masonry pier upon which the post or sill of a trestle rests.

Perch.—16½ cu. ft. in most parts of the United States; in some places 22 cu. ft.; and rarely 24¾, which was the old-fashioned perch.

Pier.—A masonry structure built to support a bridge, between the abutments; a column supporting two sequent arches. See "Abutment."

Pilaster.—A square pillar projecting from the face of a wall to the extent of one-quarter to one-third its breadth.

Pinner.—A spall or small stone used to wedge up a stone and give it better bearing.

Pitch-Line.—A well defined, straight line cut along the edge of a quarry-faced stone, but not as wide as a chisel draft.

Pitched-Face.—A face roughly dressed with a pitching chisel.

Plug and Feathered.—Split with plug and feathers; the plug being a small wedge of steel driven between two pieces of half-round steel, called feathers, which bear against the sides of the drill hole.

Pointing.—A superior class of mortar used to fill the joints in the face of a masonry wall for a depth of 1 to 3 ins.

Quarry Faced.—A rough face of stone, only the larger projections having been knocked off with a hammer.

Quoin.—See "Hollow Quoin."

Raising Stone.—See "Pedestal."

Ramp Wall.—The wing of an abutment, often called a ramp.

Random.—Not coursed.

Range Masonry.—Masonry in which the various courses are laid up with continuous horizontal beds.

Ranged.—Laid in a course of the same thickness for its full length; broken ranged masonry is laid in courses not of uniform thickness throughout each course.

Retaining Wall.—A wall that receives the horizontal thrust of earth back of it; on canal work such walls are called "vertical walls" to distinguish them from slope walls.

Ring-Stones.—The voussoirs that form the end faces of an arch, as distinguished from the "sheeting stones" that form the body of the arch.

Rip-rap.—Large stones thrown in at random to protect earth from scour by currents or waves; occasionally called "random stones." The term "hand placed rip-rap" is sometimes used to denote rough slope wall, but slope wall is a preferable term.

Rise.—The thickness (or vertical height) of a stone, measured from its lower bed to its upper bed. Do not confuse the "rise" with the "depth." The rise of an arch is the vertical distance from the spring line to the under face of the keystone.

Rock-faced.—See "Quarry-faced."

Rock-fill Dam.—A dam made of dry masonry; a rubble dam in which no mortar is used.

Rubble.—Masonry made of stones that have not been dressed,

or if dressed at all, have been only roughly shaped with a hammer, or "scabbled."

Scabbled.—Hammer dressed.

Sheeting.—The stones forming an arch. See "Ring-Stones."

Skew Arch.—An arch the plane of whose ring-stone faces forms an angle of less than 90° with the axis of the barrel. If the sheeting stones are all cut skewed, the arch is a "true skew"; but if only the faces of the ring-stones are cut on a skew, while all the other sheeting stones are cut with end joints perpendicular to the bed joints, the arch is called a "false skew."

Skewbacks.—The course of stones against which the springer stones of an arch abut.

Slope Wall.—A pavement of scabbled stones laid upon an earth slope to protect it from wash. If the stones are not scabbled, the terms rip-rap, or hand-laid rip-rap, are more appropriate.

Soffit.—The under surface of an arch.

Span.—The shortest distance between the spring lines of an arch.

Spandrel.—The triangular area bounded by the extrados of an arch, a horizontal line tangent to the extrados at the crown and a vertical line through the springing. A spandrel wall is a wall built on the extrados and filling the spandrel area; it is often miscalled a parapet wall. Spandrel filling is the earth filling between the spandrel walls.

Spall.—A fragment of stone, or stone chip.

Springers.—The lowest course of arch stones, the course resting on the skewbacks.

Springing.—Or spring line, the inner edge of the skewbacks, or the lower edge of the springers.

Squared-Stone Masonry.—Masonry in which the stones are roughly squared and roughly dressed on beds and sides.

Starlings.—The two ends of a pier.

Stretcher.—A stone laid so that its longest face forms part of the face of a wall.

Voussoir.—An arch stone.

Wing.—A spur wall at the end of a bridge abutment; also called a ramp.

Note.—Other definitions will be found at the beginning of the section on Concrete.

Percentage of Mortar in Stone Masonry.—Published tables giving the percentages of mortar in different kinds of masonry have been very misleading not only because they have been based upon meager data, but because the factors that cause variations in mortar percentages have not been discussed.

There are two ways of estimating the amount of cement required per cubic yard of masonry: (1) By estimating the percentage of mortar in the cubic yard of masonry, and then using a mortar table like that on page 253. (2) By tabulating the different kinds of masonry and giving the fractions of a barrel of cement required for a cubic yard of each kind of masonry, when the mortar is a 1:2 mixture, also when it is a 1:3 mixture—these two being the com-

mon mixtures. Each method possesses its advantages, but the first is the safest because proper allowance can be made for variations in the size of cement barrel.

A great many masonry walls consist of a "facing" of ashlar, or squared stone cut to lay close joints, and a "backing" of more or less irregular rubble stones. Obviously, if the wall is a thin one, the percentage of backing is much smaller than if the wall is thick. So that it would be desirable always to keep separate records of the amount of mortar used for the backing and for the ashlar. In practice, however, it is usually impracticable to keep separate records. The final record usually gives only the amount of cement per cubic yard of the whole wall. However, in making close estimates of probable cost it is well to keep the two classes of masonry distinct.

Knowing the average size of cut stone blocks and the thickness of joints specified, we can estimate the per cent of mortar for the face stone with considerable accuracy. Suppose the cut stone is to be in courses 12 ins. high, and dressed to lay ½-in. joints for 12 ins. back of the face. We can assume that the length of each face stone will not be far from 1½ times its thickness, or 18 ins. in this case. Hence each cut stone will contain $1 \times 1 \times 1\frac{1}{2}$, or 1½ cu. ft. Each stone must have one end and one bed mortared to a thickness of ½ in., hence we have: $1 \times 1\frac{1}{2} \times (\frac{1}{2} \div 12)$, or 0.04 cu. ft. of mortar for the end; and $1 \times 1\frac{1}{2} \times (\frac{1}{2} \div 12)$, or 0.06 cu. ft. of mortar for the bed; making a total of 0.1 cu. ft. of mortar for the end and bed of each stone. But as each stone contains 1.5 cu. ft., we see that $0.1 \div 1.5$ gives us 7% (nearly) of mortar for the cut stone.

Obviously the larger the individual stones the less is the percentage of mortar. Stones 18 ins. high, 30 ins. long, and dressed to lay ½-in. joints for 18 ins. back of the face, require 4½% of mortar.

The mortar required for the back of the stone is apparently omitted in applying the above method, but it is not omitted in the final account, since it is included in the rubble backing to a consideration of which we now pass.

Rubble is a term having wide variations in meaning, but in general it may be said to apply to masonry built of undressed stones just as they come from the quarry. Now, if the quarry is limestone or sandstone yielding flat-bedded stones, the rubble may be laid with bed joints as close as the joints of well-dressed granite ashlar. On the other hand, if the quarry is granite or rock that when blasted yields chunks of irregular shape, the rubble becomes a sort of giant concrete and requires a large percentage of mortar to fill its voids.

In any kind of rubble the percentage of mortar can be considerably reduced by packing spalls into the vertical joints between adjacent stones. As Portland cement mortar seldom costs less than $5 per cu. yd., and as spalls usually cost but a few cents per cu. yd., no pains should be spared to use as many spalls as the joints will hold.

If no spalls are used, and if the rubble is made of irregular stones,

about 35% of the rubble masonry is mortar. If the rubble is made of flat-bedded sandstone or limestone, it may contain as low as 15% mortar, but more often will average 20 to 25%.

The following are records of the actual amounts of mortar used in different masonry structures:

(1) The Medina sandstone retaining walls on the Erie Canal averaged about 10 ft. high and were faced with hammer-dressed stones and backed with flat-bedded rubble. About 22% of the wall was mortar. The mortar was 1:2, and it required about 0.63 bbl. cement per cu. yd. of wall. A barrel was counted as holding 3.8 cu. ft.

(2) Mr. A. J. Wiley states that in the Crow Creek Dam, near Cheyenne, Wyo., there are 14,420 cu. yds. of rubble masonry, of which 34¾% was mortar. About 80% of this mortar was 1 Portland cement to 4 sand; the rest was 1 to 3. Each barrel was counted as 4 cu. ft., and 8,844 bbls. were used, or 0.62 bbl. per cu. yd.

(3) The Cheesman Dam is of rubble, with one ashlar face, and is said to contain 28% mortar.

(4) The Cheat River Bridge, on the B. & O. R. R., near Uniontown, Pa., has five piers and two abutments. The masonry is a first-class sandstone facing with a rubble backing of heavy stones, and the mortar was 1 of Louisville (natural) cement to 2 of sand. There were 3,710 cu. yds. of masonry, which required 1,500 bbls. of cement (shipped in bags), or 0.4 bbl. per cu. yd.

(5) The masonry locks on the Great Kanawha River, West Virginia, were built of sandstone obtained at Lottes, W. Va. Face stones were cut to lay ½-in. bed-joints and 1-in. vertical joints Backing bed-joints were 1 in. The mortar was 1 part Rosendale cement (Hoffman brand), to 2 parts sand. It required 0.36 bbl. per cu. yd. of masonry.

(6) A curved masonry dam, 82 ft. high, built at Remscheid, Germany, is made of slate having a specific gravity of 2.7. The masonry, laid in trass mortar, weighs 4,015 lbs. per cu. yd. Owing to the irregular form of the stones the mortar was 38% of the masonry.

(7) The Holyoke Dam, 30 ft. high, is of rubble masonry with a cut granite face. The mortar was 1 Portland cement to 2 sand, and it is stated that 0.87 bbl. of cement was required per cubic yard of rubble masonry.

(8) Masonry in bridge piers, at Van Buren, Arkansas River, was for the most part of white limestone. In 10 piers there were 4,500 cu. yds. of masonry, which averaged 0.57 bbl. natural cement per cu. yd. The beds and joints were 1:2 mortar, and a 1:1 grout was also used.

(9) The limestone masonry for the Sault Ste. Marie locks (U. S. Government) amounted to 80,876 cu. yds., of which 23% was cut stone, 60% backing and 17% mortar. The cut stone blocks average 1.3 cu. yds. each, and were dressed to lay ⅜-in. vertical joints for 18 ins. back of the face, and the bed joints were dressed to ⅜ in.

the full depth of the stone. In cutting the stone there was a wastage of 26½% of stone. The mortar was 1 : 1, and it required 0.29 bbl. of Portland cement per cu. yd. of cut stone, 1.21 bbls. of natural cement per cu. yd. of backing, and 0.78 bbl. per cu. yd. of the wall, including cut stone and backing. The backing stones each averaged 8 sq. ft. bed area, and no bed-joint was greater than 1 in.; and no vertical joint exceeded 4 ins., the average being 2 ins. This is remarkably close jointing for backing, and was unquestionably very expensive to secure.

(10) The Lanchensee Dam, Germany, was made of graywacke rubble (stones ⅓ to ½ cu. yd. each); 35% of the dam was mortar. A force of 45 masons, 12 helpers, 27 laborers and 4 foremen worked on the dam, and 110 men at the quarry. They averaged 120 cu. yds. of masonry per day, the best day's work being 196 cu. yds. Eight locomotive cranes running on trestles took the stone from the cars. The work was done by day labor for the German Government.

(11) The Sweetwater Dam, California, was built of a granitic rubble that was quarried in irregular chunks. Mortar was 1 : 3, proportioned by barrels, and it required 0.86 bbl. cement per cu. yd. of rubble masonry.

Cost of Laying Masonry.—According to my experience on numerous small culvert bulkheads made of limestone or sandstone rubble, one mason with a helper to mix mortar and "get stone" will lay 4 to 5 cu. yds. per 8-hr. day. If mason's wages are $3 and helper's $1.50 this makes the cost average $1 per cu. yd. for laying. No derrick is used in such work the stone being one-man or two-man stone. Moreover, the stone requires little or no hammer-dressing on the part of the mason.

In laying dry slope-walls (12 or 15 ins. thick) where stone of the same kind as the above is used, requiring very little hammer-dressing, a slope-wall mason will lay 5 to 7 cu. yds. per 10-hr. day, and I have had a man lay as high as 12 cu. yds. per day. One laborer to about 2 or 3 slope-wall masons is required, to furnish them with stone. A common laborer will lay about half as many yards of slope-wall stone as a skilled mason, so there is little or no economy in using unskilled labor in laying the stone that must be laid to a line and occasionally dressed with a hammer.

On a highway arch bridge of 30-ft. span, with a barrel 20 ft. long, there were 50 cu. yds. of cut stone sheeting, 30 cu. yds. of cut stone facing in the abutments and walls, and 190 cu. yds. of limestone rubble in the abutments and walls. The masonry was laid by a mason and 3 laborers, two of the laborers operating a hand power derrick and getting stone for the mason, while the third laborer made mortar and also assisted in getting stone. This gang worked without a foreman and were very slow, since they averaged only 3 cu. yds. per 8-hr. day. With mason's wages at $3 and laborers' at $1.50, the cost of laying the masonry was $2.50 per cu. yd. This included the erecting of two small derricks on opposite sides of the stream, but did not include erecting the centers for the arch. On page 206, the cost of laying the masonry of an arch bridge, similar

to this one is given in detail; it being $1.35 per cu. yd., which shows how easy it is to reduce the cost of laying where the men are better organized. The common mistake made in organizing forces for laying stone with hand operated derricks is in having too many laborers to one mason, who is unable to keep them busy.

If the mason must hammer-dress the stone to a great extent, as is often required by inspectors on granite rubble arches, the cost of laying (including this hammer dressing) may amount to $3.50 per cu. yd. It is difficult to be definite in the matter of costs of hammer-dressed granite rubble, because inspectors vary so extremely in their interpretation of specifications. If no hammer-dressing is required (and none should be required for backing laid in cement mortar), the cost of laying granite rubble need not exceed the cost of laying limestone or sandstone rubble, say $1 per cu. yd., wages being as above given.

In tearing down and relaying an old masonry retaining wall (9 ft. high), the author employed 16 laborers and 2 masons under a foreman. A stiff-leg derrick having 30-ft. boom, and operated by hand, was used to handle the heaviest stones. Much of the backing was laid by hand by the laborers. This gang averaged 36 cu. yds. of masonry laid per 10-hr. day, at a cost of $30, exclusive of foreman's wages, or less than 85 cts. per cu. yd. It cost 75 cts. per cu. yd. to tear down the wall before relaying it.

For laying any considerable quantity of masonry, never use a hand-operated derrick. A horse-whim forms cheaper power than two men on a winch. But in either case the lost time of swinging, or slewing, the boom cannot be avoided. The men (usually two) who swing the boom are called "tag men," because they pull the boom back and forth with "tag ropes." The wages of these men form a surprisingly large part of the cost of laying stone where a derrick is used which is not provided with a "bull-wheel" for swinging the boom. The engineman controls the swinging of the boom where a bull-wheel is used, and can make a swing of 90° in 15 to 20 seconds.

To show how rapidly stone may be handled with a 60-ft. boom derrick, the following record will serve:

	Seconds.
Hooking on to skip	35
Swinging boom 90°	20
Dumping skip	15
Swinging back 90°	20
Total	90

This is equivalent to 400 skip loads in 10 hrs.; and, were the material supplied and removed fast enough, the derrick could readily maintain this output for 10 hrs., handling 1 cu. yd. of rubble in each skip load. Obviously in masonry work, where a bull-wheel derrick is used, the limiting factor is the amount of stone the masons can handle per day. Much of the derrick time is spent in the puttering work necessary in carefully placing large stones in the wall. Now, where tag-rope men are used instead of a bull-wheel, prac-

tically all their time is wasted, as they spend so little of the day doing active work.

Further data on the cost of laying masonry will be found on subsequent pages.

Estimating the Cost of Stone Dressing.—Stone may be divided into two classes: (1) Stone stratified in beds of a thickness not much exceeding 30 ins.; and (2) stone that is either unstratified, or occurs in beds of such thickness that the blocks must be split with plugs and feathers to secure sizes which can be handled with a derrick.

Many sandstones and limestones occur in thin strata or layers, and, after the use of a little black powder to "shake up" the ledge, it is possible to quarry blocks with wedges and bars. These blocks will often be as smooth as a floor on the bed-joints, but may be quite irregular on the vertical joints. However, either by hammering, or by plug and feathering, the vertical joints can be squared up at slight expense ready for further dressing if required by the specifications. On the other hand, all granites and many thick-bedded limestones and sandstones, break out in such irregular shapes that it often happens that every face must be plug and feathered before the block is roughly squared up ready to be dressed by the stonecutters. Obviously the dressing of the beds of such stones is far more expensive than the dressing of the beds of smoothly stratified stones.

Besides differences in hardness, we see that the shape of the stones as they come from the quarry is a very important factor in the cost of dressing.

Another factor of scarcely less importance is the size of the blocks of stone. It is generally possible to quarry granites in blocks of any desired size, the limit being fixed by the strength of the derricks and other machinery used. A very common size of granite blocks dressed ready to lay in the wall is 18 ins. rise x 40 ins. length x 24 to 30 ins. depth. And as every block of granite must be plug and feathered to size before dressing, it is just as cheap to make coursed ashlar as random range ashlar. On the other hand, stratified rocks like sandstone usually occur in layers of different thickness, and it may be impossible to secure enough stone for courses of a specified rise without wasting a large part of the quarry product. An engineer should never specify any given "rise" for the courses (except in granite), until he has examined the quarries and is sure that they will yield the product specified. But engineers often fail to do this, and the contractor must be careful not to be equally foolish in failing to examine the stone available.

Stone is often so seamy or so brittle that it can be quarried only in small chunks. Now it is obvious that the smaller the chunk the greater the area that must be dressed per cubic yard; but how greatly this factor affects the cost of dressing is seldom considered. To illustrate, let us assume that blocks for ashlar are each 12 ins. rise x 24 ins. long x 18 ins. deep. Each block then contains

3 cu. ft., and has 6 sq. ft. of bed joints and 3 sq. ft. of end joints, or 9 sq. ft. of joints to be dressed. Let us now take an ashlar block 18 ins. rise x 36 ins. long x 24 ins. deep. This block contains 9 cu. ft., and has 12 sq. ft. of bed joints and 6 sq. ft. of end joints, or 18 sq. ft. of joints to be dressed. With the smaller block we have 9 x 9, or 81 sq. ft. of joints to be dressed for every cubic yard; whereas with the larger block we have 3 x 12, or 36 sq. ft. to be dressed for every cubic yard. In other words the cost of dressing ashlar of the 3-cu. ft. blocks is more than twice as expensive per cubic yard as the cost of dressing the 9-cu. ft. blocks.

It is apparent, therefore, that all records of the cost of dressing stone should be expressed in terms of the square feet actually dressed, and then the data can be applied to blocks of any given size to obtain the cost of dressing per cubic yard. This method of estimating costs will often lead a contractor to import his stone a long distance by rail rather than attempt to dress the small-sized stones from local quarries.

It is customary among contractors and stonecutters to speak of so and so many "square feet" of stone dressed per day, meaning not the number of square feet of beds and joints dressed, but the square feet of "face." For example a stone is 1½ ft. rise x 3 ft. long x 2 ft. deep. This stone when laid lengthwise in the face of a wall will show a face area of 4½ sq. ft., and the stone cutter is said to have dressed 4½ sq. ft. As a matter of fact he has dressed 12 sq. ft. of bed joints, and 6 sq. ft. of end joints, beside plugging off or hammering the face of the stone, and cutting the drafts if specified. In my early work I was misled by this method of estimating stone dressing in terms of the square feet of face. It is a method that should be abandoned.

Data of the actual cost of stone dressing will be given in subsequent pages.

Data on Stone Sawing.—There is little on this subject in print, but in almost any large city stone saws may be seen at work, and a rough estimate can be made of the cost of stone sawing. To tell how many inches deep a saw cuts in a day, examine a slab of stone newly cut in the yard. It will be noted that there are rust lines on the face of the slab. The distance between these lines indicates the depth cut in a day, for when the saws are idle at night, the rust forms.

For cutting stone into thin slabs, it is common practice to run two "gangs" of saws, of 15 saws in a "gang" driven by a small engine. As nearly as I have been able to estimate by observation and inquiry, the daily cost of operating a "two-gang" plant is as follows per 9-hr. day in New York City:

1 gangman	$ 4.00
1 helper	3.00
2 cu. yds. sand, at $3	6.00
½ ton coal, at $6	3.00
Total per day	$16.00

Working in Tennessee marble each saw cuts about 6 ins. deep per day, therefore, if the block is 6 ft. long, the 30 saws cut 90 sq. ft. per day of 9 hrs. The cost of sawing slabs, therefore, approximates 17 cts. per sq. ft. The saw cuts a kerf ⅛-in. wide.

I am told that with wages of polisher at $3.50, slabs can be polished by hand at 6 cts. per sq. ft.; but where the polishing is done by machine the cost is about 2½ cts. per sq. ft.

Wages of stone yard men in New York City are about a third higher than in most other American cities.

Mr. R. J. Cooke states that the rates of sawing different kinds of stone are as follows:

	Depth cut in 10 hrs., ins.
Granite, Addison, Me. (shot)	10
Granite, Chester, Mass. (sand)	12
Granite, Red Beach, Me. (shot)	7½
Bluestone, Hudson River (sand)	8
Marble, Carara, Italy (sand)	15
Marble, Tennessee (sand)	9
Marble, Tate, Ga. (sand)	6
Marble, Tate, Ga. (sand)	12
Marble, Gouverneur, N. Y. (sand)	12
Marble, W. Rutland, Vt. (sand)	20
Marble, Proctor, Vt. (sand)	15
Limestone, New Point, Ind. (sand)	10
Limestone, New Point, Ind. (sand)	15
Oolitic limestone, Bedford, Ind. (sand)	40
Oolitic limestone, Bedford, Ind. (sand)	70
Magnesian limestone, Lemont, Ill. (sand)	36
Sandstone, N. Amherst, O. (sand)	40
Sandstone, Clarksville, O. (sand)	36
Brownstone, Portland, Conn. (shot)	20
Brownstone, Hummelston, Pa. (shot)	25

The Young & Farrell Diamond Stone Sawing Co., of Chicago, classifies stone into soft, medium and hard; soft includes sandstones; medium includes limestones, and hard includes marbles and granites. They say (1890) the cost of sawing per sq. ft. is: Soft, 8 to 10 cts.; medium, 13 to 17 cts.; hard, 25 to 30 cts.; all on the basis of 4-in. sawing or two cuts to the cubic foot. With wages of stone cutters at 50 cts. an hour, the cost of hand dressing the same classes of stones is given as follows per square foot: Soft, 25 to 30 cts.; medium, 40 to 45 cts.; and hard, 75 to 80 cts.; all clear face work.

Cost of Stone Dressing.—In addition to the data just given, The Syenite Granite Co., of Graniteville, Mo., say (1890) that the cost of hand dressing 36,000 cu. ft. of granite to ½-in. joints was 20 cts. per sq. ft., not including blacksmithing, handling, etc., which was 6 cts. more per sq. ft. This stone was granite cut to lay in 24 to 30-in. courses for the Merchants' Bridge, St. Louis, and it was delivered for $1.15 per cu. ft.

The Kankakee Stone & Lime Co. say (1890) that, with wages at $2 a day, the cost of dressing limestone (bush-hammered or drove-work) is 25 cts. per sq. ft.

Cost of Cutting Limestone and Sandstone.—In dressing Medina

sandstone, a stonecutter will dress enough stone in 9 hrs. to lay 12 sq. ft. of face in a wall having courses that average 15 ins. rise, which is equivalent to about 0.9 cu. yd. of face stone per day, or 30 sq. ft. of beds and joints cut to lay ½-in. joints for at least 12 ins. back of the face. The face is rock-faced, and is plugged off by the stonecutter.

In dressing limestone for arch sheeting, the author made the mistake of using a quarry whose product was all small and gnarled stones. Each stone after dressing averaged only 11 ins. thick, 22 ins. long, and 18 ins. deep, or about 0.1 cu. yd. per stone, so that to secure 1 cu. yd. of this cut-stone required the dressing of 80 sq. ft. of beds and joints. Each stonecutter averaged 36 sq. ft. of beds and joints (dressed to lay ½-in.) per 9-hr. day, or 1 cu. yd. in 2¼ days. These cutters received 40 cts. per hour.

Cost of Sandstone Bridge Piers.—The cost of cutting 246 cu. yds. sandstone to ½-in. joints for bridge piers was $2.65 per cu. yd.; the cutting of the stones for the nose of the pier cost $3 per cu. yd. The wages of cutters were 38 cts. per hr.

The cost of loading the stone, train service, sand, cement and laying the masonry was $3.60 per cu. yd. About ⅛ bbl. of Portland cement costing $2.40 per bbl. was used per cu. yd. of masonry. The cost of quarrying the stone was $1.65 per cu. yd. The total cost of the pier masonry was $9 per cu. yd. For the foregoing data I am indebted to Mr. C. R. Nehr.

Cost of Cutting Granite for a Dam.—In building a dam in the northern part of New York state, the author used a granitic rock. The face stones were cut to lay in courses with beds and joints ⅝ in. thick. Each cut stone was quarry-faced and averaged 1½ ft. rise x 3 ft. long x 2 ft. deep, or about ⅓ cu. yd. A stonecutter averaged one such stone per 8-hr day, or 18 sq. ft. of beds and end joints dressed per day. A blacksmith, at $2.50, and a helper, at $1.50, sharpened the points and plug drills for 8 stonecutters. The cost of cutting this face stone was as follows:

	Per cu. yd.
Stone cutters, at $4 per 8 hrs.	$12.00
Blacksmithing	1.20
Labor bankering stones and plugging off faces	1.80
Sheds and tools	0.80
Superintendence	1.20
Total	$17.00

On a small portion of the work the stone was dressed to lay ¼-in. joints, which added $6 per cu. yd. to the cost.

Cost of Cutting Granite, New York City.—Mr. Wm. W. Maclay gives the cost of cutting 2,065 cu. yds. of granite by a force of 40 stonecutters working for the New York Department of Docks, during 1873 to 1875. The working day was 8 hrs. The following table gives the average day's work of a stonecutter working for the Dock Department as compared with work done for contractors in New York:

Cutting Granite.	Sq. ft. per 8-hr. day. For Dock Dept.	For Contractors.
Dressing beds and joints (¼ in.)...............	13.5	16.0
Pointed work with 1½-in. chisel draft all around	8.5	10.0
Pean-hammered	6.0	7.25
6-cut patent hammered........................	5.25	6.15
8-cut patent hammered........................	4.25	5.00

It will be noted that the men working for the Dock Department did about 15% less work daily than is said to have been the average under contractors.

In doing this dock work there were 1,524 cu. yds. of dimension stones cut into headers and stretchers. The headers averaged 2 ft. on the face by 3 ft. deep; and the stretchers averaged 6 ft. long on the face by 3 ft. deep; the rise being 20, 22 and 26 ins. for the different courses. The stones were cut to lay ¼-in. beds and joints, the faces being pointed work with a 1½-in. chisel draft all around. The cost of this cutting was as follows:

	Per cu. yd.	Per cent.
Cutting (4.53 days)	$13.22	48
Labor rolling stones........................	8.26	30
Sharpening tools	4.13	15
Superintendence	1.38	5
New tools and timber for rolling stones.........	0.28	1
Interest on sheds, derrick, and railroad.........	0.28	1
Total	$27.55	100

In addition to this work there were 310 cu. yds. of coping cut to lay ¼-in joints, pointed on the face and with a chisel draft, 8-cut patent-hammered on the top, and with a round of 3½-in. radius. The coping stones were 8 ft. long, 4 ft. wide, and 2½ ft. rise. The cost of cutting this coping was as follows:

	Per cu. yd.	Per cent.
Cutting (6.26 days)	$18.27	48
Labor rolling stones........................	11.42	30
Sharpening tools	5.71	15
Superintendence	1.90	5
New tools and timber........................	0.38	1
Interest on sheds, etc........................	0.38	1
Total	$38.06	100

It would appear from the above that the stonecutters received $3 for 8 hrs., but Mr. Maclay states that the pay was $4 for 8 hrs. If so there is some error in the other items, which I have calculated from the percentages given by him. It is difficult to understand how the "labor of rolling stones" could have been 30% of the total cost of cutting, unless the laborers assisted in plug and feathering the stones preparatory to cutting. The cost of tool sharpening (15%) was also very high Certainly these two items were much higher than they would have been under a contractor.

Mr. J. J. R. Croes states that in cutting granite for the gate-houses of the Croton Reservoir at 86th St., New York, in 1861-2, the least day's work was fixed at 15 sq. ft. of beds and joints. This included the cutting of a chisel draft around the face of the stone, the cost of which was about one-fourth as much as cutting a square foot of

joint, making the actual least day's work equivalent to 17.7 sq. ft. of beds and joints cut. With wages of stonecutters assumed at $3 per day, from the percentages given by Mr. Croes, I have calculated the cost of cutting to have been as follows per square foot:

	Per sq. ft.
Cutting (15 sq. ft. per day)	$0.200
Sharpening tools	0.022
Labor moving stone in yards	0.020
Drillers plugging off rough faces	0.008
Superintendence	0.016
Sheds and tools	0.014
Total	$0.280

The cost of all the items other than the wages of stone cutters was 40% of the wages of the stonecutters, or 8 cts. per sq. ft.

Cost of Quarrying, Cutting and Laying Granite.—Mr. J. J. R. Croes gives the following data relative to work done on the Boyd's Corner Dam, near New York City:

The stone is a gneiss that is about as difficult to quarry as granite. The face stone for the dam average 1.8 ft. rise, 3.6 ft. long and 2.7 ft. deep, and were cut to lay ¾-in. joints. In quarrying the dimension stone, plug and feathers were used to split the stone to size ready for cutting. The cost of quarrying and plug and feathering 4,000 cu. yds. of dimension stone ready for cutting was as follows:

	Days (10 hr.) per cu. yd.	Cost per cu. yd.
Foreman, at $3	0.114	$0.34
Drillers, at $2	0.917	1.84
Laborers, at $1.50	0.429	0.65
Blacksmiths, at $2.50	0.102	0.25
Tool boys, at $0.50	0.108	0.05
Labor loading teams, at $1.50	0.284	0.42
Total (not including explosives and teaming)		$3.55

The work was done by contract in 1867-8. The rates of wages were not given by Mr. Croes, but Mr. John B. McDonald has been kind enough to give me most of the rates of wages as nearly as he can remember. The length of haul from quarry to stone yard was about a mile, and Mr. McDonald states that oxen were used. The cost of "teams" is given by Mr. Croes, as 0.62 team day per cu. yd., which indicates that a good deal of stone boat work was done, or else that there is an error in this item.

The cost of quarrying 3,400 cu. yds. of rubble stone for this same dam was as follows:

	Days per cu. yd.	Cost per cu. yd.
Foremen, at $3	0.041	$0.12
Drillers at $2	0.339	0.68
Laborers, at $1.50	0.140	0.21
Blacksmiths, at $2.50	0.036	0.09
Tool boy, at $0.50	0.035	0.02
Labor, loading teams, at $1.50	0.077	0.12
Teams, at $4	0.141	0.56
Total labor		$1.80

It is presumable that both the dimension stone and the rubble stone were measured in the dam.

The masonry was called "rubble range"' a term that deceived most of the contractors, for the specifications in fact called for stones cut to lay in courses with ¾-in. *bed* joints. During 3½ years of work there were 5,200 cu. yds. of this "rubble range" cut, requiring the dressing of 6,373 sq. ft. Each stone averaged 1.8 ft. rise, 3.6 ft. long, and 2.7 ft. deep, or 0.65 cu. yd. per stone. Each stonecutter averaged 18.7 sq. ft. of bed joints dressed per day, so that it took 1.57 days to dress each cubic yard of "rubble range" stone.

The ashlar stones were called "dimension cut-stone masonry", and were cut to lay ¼-in. joints both on bed and end joints, and the faces were pean hammered. The lowest bid on this ashlar was $30 per cu. yd., but another contractor, who had previously done the same kind of work, bid $60 per cu. yd.

It took 9 days' work of a stonecutter to dress each cubic yard of this ashlar.

The coping was laid in two courses; one course of stones 12-in. rise, 30-in. bed, and 3½-ft. length; the other course, 24-in. rise, 48-in. bed, and 2½-ft. length. The top was pean hammered, and the face was left rough with a chisel draft around it. The beds and joints were cut to lay ¼-in. It took a stonecutter 6.1 days to dress each cubic yard of this ashlar.

The cost of laying the masonry in the dam was as follows, wages being assumed to be approximately what they are now (not what they were in 1875):

	Cost per cu. yd.			
	A	B	C	D
Mason, at $3.00	$0.36	$0.36	$0.25	$0.32
Laborers, at $1.50	0.28	0.28	0.22	0.23
Mortar mixers, at $1.50	0.15	0.12	0.11	0.15
Derrick and carmen, at $1.50	0.49	0.51	0.36	0.39
Engine, at $4.00	....	....	0.18	0.20
Teams from yard, at $3.50	0.35	0.20	0.20	0.39
Laborers loading teams, at $1.50	0.28	0.33	0.33	0.13
Total	$1.91	$1.80	$1.65	$1.81

Columns A and B relate to work done in 1868 and 1869 when the stone was hoisted by hand; A was a lift of 5 ft., B was a lift of 10 to 20 ft. Columns C and D relate to work done in 1869 and 1870, when the hoisting was done by engines; C being a lift of 20 to 30 ft.; D being a lift of 30 to 50 ft. It will be noted that each mason laid from 8½ to 12½ cu. yds. per day. Each engine apparently served two masons, but it is not stated whether each mason had a separate derrick or both worked with one derrick.

The stones were laid in inclined or sloping courses, which made it hard to keep them in place as a rap of a hammer would cause sliding.

It will be noted that the cost of loading and hauling the stone from the stone yard to the dam is included in the above costs of laying. This cost of loading and hauling is not properly a part of the cost of laying.

The mortar was a 1:2 mixture, natural cement, and it required

0.3 bbl. of cement, 0.093 cu. yd. sand, and 0.89 cu. yd. of stone per cu. yd. of dam masonry. In other words, only 11% of the masonry was mortar.

Cost of Plug Drilling by Hand.—By timing a number of masons at work splitting granite blocks 24 to 30 ins. thick, I found that each man drilled each hole (⅝-in. diam. x 2½ ins. deep) in a trifle less than 5 mins., by striking about 200 blows. It took about 1 min. for placing and striking each set of plug and feathers. A block 30 ins. long, with four plug holes, was drilled and split with the plugs and feathers in 24 mins., on an average. At this rate, a good workman can drill and plug 80 holes in 8 hrs., but it is not safe to count upon so large an average.

Cost of Pneumatic Plug Drilling.—For drilling plug holes in granite certainly no tool is as economic as the pneumatic plug drill. Horizontal as well as vertical holes can be rapidly drilled. The ordinary plug drill, according to the manufacturers, consumes 15 cu. ft. of free air per min. at 70 lbs. pressure. At the Wachusett Dam I found that a workman averaged one hole (⅝-in. diam. x 3 ins.) drilled in 1½ mins., including the time of shifting from hole to hole, but not including the time of driving the plugs. About 250 plug holes are counted a fair day's work for a plug drill where the driller does not drive the plugs himself.

Cost of Quarrying Granite.—Cost data relating to the quarrying of granite dimension stone are extremely hard to secure. I have been able to find only one writer, Mr. J. J. R. Croes, who has published anything on the subject. Mr. Croes' records, together with mine, will at least form a basis for approximate estimates of cost of granite quarrying. My data apply to quarrying three-dimension stone in a sheet quarry on the coast of Maine. The total number of men engaged was, on the average: 6 enginemen, 6 steam drillers, 6 drill helpers, 3 blacksmiths, 3 helpers, 5 tool and water boys, 38 quarrymen, 47 laborers, 2 foremen and 1 superintendent. This force quarried and loaded on boats about 1,400 cu. yds. of rough granite blocks. The stone was loaded by derricks onto cars from which it was unloaded into boats ready for shipment. The following cost includes everything except interest and depreciation of plant, and development expenses:

	Cost per cu yd.
Enginemen, at $2 a day (of 9 hrs.)	$0.20
Steam drillers, at $2.00	0.20
Drill helpers, at $1.50	0.15
Blacksmiths, at $2.75	0.14
Blacksmiths' helpers, at $1.75	0.09
Tool and water boys, at $1	0.16
Quarrymen, at $1.75	1.09
Laborers, at $1.50	1.15
Foremen, at $3.00	0.15
Superintendent, at $8	0.20
Coal, at $5 ton	0.45
Explosives	0.25
Other supplies	0.30
Total	$4.53

On the best month's work, when a larger force was being operated, the cost of all labor, superintendence and supplies, was reduced to a little below $4 per cu. yd., but the above $4.50 per cu. yd. may be taken as a fair average of several months' work. To this should be added the charges for plant rental, quarry rental (if any), stripping (if any), and freight charges to destination. The freight rate by boat from Maine to New York is about $1 a ton, but as rough granite blocks are always measured on their least dimensions, the freight charges when $1 per ton amount to about $2.70 per cu. yd. of three-dimension stone in the rough. The explosives used were black powder, costing $2.25 a keg (25 lbs.), and dynamite for channeling, costing 15 cts. a lb. The sheet from which this granite was quarried averaged about 6½ ft. thick, and was nearly flat. The stone was loosened in long blocks by Knox blasting with black powder, and was split up into sizes by plug and feathering; both hand drills and pneumatic plug drills being used for this purpose. The stone, as before stated, was three-dimension stone. To quarry random stone (not rubble) in this quarry cost about $3.50 per cu. yd.

If granite is blasted out in all shapes and sizes, to be used for rubble or for concrete, the cost of quarrying is far less than the above and is approximately the same as quarrying trap rock, provided the two kinds of rock are equally seamy or jointed. Traps, however, are usually much more seamy than granites; hence the drill holes in trap can usually be spaced much farther apart than in granite having few seams.

Cost of a Masonry Arch Bridge.—This arch bridge had a span of 30 ft., and its barrel was 60 ft. long. The masonry was limestone laid in Portland cement mortar. There were 365 cu. yds. of masonry distributed as follows:

	Cu. yds.
Arch sheeting	112
Bench walls (or abutments)	165
Backing above arch	17
Backing above haunch	38
Wing walls	21
Parapet walls	7
Coping	5
Total	365

The arch sheeting masonry was dressed to lay ⅝-in. joints, and the cost of these 112 cu. yds. was as follows:

	Cu. yd.
Quarrying rough blocks	$ 1.00
Plug and feathering into blocks	0.85
Hauling and loading onto car	0.75
Freight	1.05
Unloading from car and hauling 1 mile	0.70
Cutting	4.55
Laying	1.35
Mortar	1.50
Centers	2.20
Total	$13.95

This sheeting was cut to lay an arch 18 ins. thick, each block averaging 12 x 18 x 28 ins. in size, or about ⅛ cu. yd. The blocks were small, but the quarry did not yield large material. Quarrymen were paid 30 cts. per hr. and helpers 17½ cts. per hr. The unloading from cars onto wagons cost 35 cts. per cu. yd., wages being 15 cts. per hr.; and the hauling 1 mile cost 35 cts. per cu. yd., teams being 40 cts. per hr.

The stonecutters were paid 35 cts. per hr., and their work cost $4.25 per cu. yd.; the sharpening of cutters' tools cost 15 cts. more per cu. yd.; and the help of laborers occasionally in bunkering a stone cost another 15 cts. per cu. yd.; making a total of $4.55 for cutting the stone after it had been plug and feathered roughly into blocks. The small size of the blocks made this cost high.

The stone was laid by a hand-power derrick, the cost of laying being in detail as follows:

	Per cu. yd.
Masons, at 30 cts. per hr.	$0.80
Helpers, at 15 cts. per hr.	0.45
Team on stone boat, 40 cts. per hr.	0.10
Total cost of laying	$1.35

Each mason had 1¼ helpers and laid 3 cu. yds. in 8 hrs. This was the average of all the 365 cu. yds. of masonry; the cost of laying each kind was not kept separately.

The mortar was 1:3 Portland cement, allowing 4.5 cu. ft. per bbl.; it took 2 bbls. of cement and 0.9 cu. yd. sand to make 1 cu. yd. mortar; and the cost of these materials was $4.50 per cu. yd. of mortar. It took ⅓ cu. yd. of mortar for each of the 365 cu. yds. of masonry; no attempt was made to determine the amount of mortar for each kind of masonry.

The cost of the ashlar facing in the abutments and wing walls was the same per cubic yard as the arch sheeting after deducting the $2.20 for centers, that is $11.75 per cu. yd.; and there were about 50 cu. yds. of this in the bridge.

The cost of the rubble backing in the abutments, haunch, etc., of which there were nearly 200 cu. yds., was as follows:

	Per cu. yd.
Rubble sandstone delivered at bridge	$1.20
⅓ cu. yd. mortar, at $4.50	1.50
Laying	1.35
Total	$4.05

This rubble was a local sandstone, but the ashlar was a limestone imported by rail.

The foregoing costs do not include foreman's salary and general expenses, which amounted to 15% of the total cost of the bridge. In addition to the 365 cu. yds. of stone masonry there were 65 cu. yds. of concrete foundations laid on a hard clay. There was no cofferdamming.

The cost of the work was higher than it would have been under a better foreman.

Cost of Centers for 30-ft. Arch.—Centers for a masonry arch of

30-ft. span and having a barrel 60 ft. long were made of hemlock. There were 21 arch ribs or centers spaced 3 ft. apart and lagged with hemlock 2 ins. thick by 6 ins. wide. Each center was made of two thicknesses of 2 x 12-in. plank cut in section 6 ft. long and spiked together, breaking joints. The ribs were cut to the curve of the arch at a saw mill. The following was the bill of timber in each center:

	Ft. B. M.
6—2-in. x 12-in. x 12-ft. curved ribs	144
4—2-in. x 6-in. x 16-ft. ties	64
1—2-in. x 6-in. x 10-ft. splices	10
1—2-in. x 6-in. x 10-ft. post	10
2—2-in. x 6-in. x 16-ft. struts	32
Total per bent	260
22 centers at 260 ft. B. M.	5,720
Lagging 2 ins. x 33 ft. x 60 ft.	3,960
Total	9,680

The machine work at the mill cost $20, and the carpenter work of framing the centers was $7.75 for carpenters at 22½ cts. per hr. and $9.25 for carpenters' helpers at 15 cts. per hr., making a total of $37. This is equivalent to $6.50 per M when distributed over the 5,720 ft. B. M. in the centers. The cost of erecting the centers with the aid of a hand-power derrick together with the cost of placing the lagging was $24, all this work being done by laborers at 15 cts. per hr. This $24 distributed over all the 9,712 ft. B. M. is $2.56 per M. The cost of removing the centers after completion of the work was $10, wages being 15 cts. per hr., or $1.05 per M. The total cost of the centers was:

9,712 ft. B. M. hemlock, at $16	$155.51
132 oak wedges, at 10 cts.	13.20
230 lbs. wire nails, at 3½ cts.	8.05
Machine work at mill	20.00
Work framing centers	17.00
Work erecting centers	24.00
Work tearing down centers	10.00
Total	$247.76

It will be noted that the millwork and labor cost $71, which is equivalent to $7.30 per M distributed over the 9,712 ft. B. M. There were 112 cu. yds. of masonry in the arch alone, so that the cost of the centers distributed over the arch sheeting was $2.20 per cu. yd. But there were 250 cu. yds. of masonry, all told, in the arch, the abutments, parapet and wing walls. The short posts supporting the centers rested on hard clay.

Cost of Arch Culverts and Abutments, Erie Canal.—In 1840 contracts were let for enlarging the Erie Canal. The courts later declared the law making the appropriation unconstitutional and the New York State Legislature directed that the contracts be canceled and that contractors be paid their prospective profits. The 12 engineers in charge of the work submitted the following estimates of the actual cost. The stone in masonry was limestone from the lower Mohawk valley. Masons and stonecutters were paid $2.25 per day

of 11 hrs. worked, laborers $1. The cost of masonry in arch culverts and bridges was as follows:

Face stone:	Per cu. yd.
Quarrying, 1 cu. yd. per man day	$2.25
Cutting, 1.3 cu. yds. per man day	2.25
Laying, 0.7 cu. yd. per man day	1.25
Mortar	0.75
Total, not including hauling	$6.50

Note: The cost of quarrying includes sharpening drills, foremen, etc.

Backing (rubble):	
Quarrying, 2 cu. yds. per man day	$1.00
Laying, 1.75 cu. yds. per man day	1.00
Mortar	1.25
Total, not including hauling	$3.25
Arch sheeting:	
Quarrying, 1 cu. yd. per man day	$2.25
Cutting, 0.88 cu. yd. per man day	3.25
Laying, 0.7 cu. yd. per man day	1.25
Mortar	1.00
Total, not including hauling, or centers	$7.75
Ring and Coping:	
Quarrying, 0.6 cu. yd. per man day	$ 3.40
Cutting, 0.55 cu. yd. per man day	5.00
Laying, 0.58 cu. yd. per man day	3.00
Mortar	0.50
Total, not including hauling	$11.90

The cost of hauling stone 1 mile from quarry to canal was 50 cts. per cu. yd., 7 round trips being made per day by a team hauling ¾ cu. yd. of stone, as measured in the work.

The centers for arch culverts of 4 to 8-ft. span were estimated to cost 50 cts. per cu. yd. of arch masonry. For spans of 10 to 15 ft. the centers cost 75 cts. per cu. yd. of arch masonry.

Timber stringers covered with 2 or 3-in. plank were largely used for foundations and floors of culverts. The cost of placing such timber was $4 per M.

Cost of Lock Masonry, Erie Canal.—The following is a continuation of the data just given:

The masonry for locks was dressed as follows: Cut stone face, ⅛-in. joints; hammer dressed backing, 1-in. joints. Wages were as above given.

Lock face stone:	
Quarrying, 0.67 cu. yd. per man day	$ 3.00
Cutting, 0.50 cu. yd. per man day	5.50
Laying, 3.00 cu. yds. per man day	0.83
Mortar	0.50
Machinery	0.25
Total, not including hauling	$10.08

Lock backing (1-in. joints):	
Quarrying, 1 cu. yd. per man day	$2.00
Cutting, 1.8 cu. yds. per man day	1.50
Laying, 4 cu. yds. per man day	0.62
Mortar	0.75
Machinery	0.25
Total, not including hauling	$5.12

The average cost of lock masonry, including face and backing, was $1.70 per cu. yd., exclusive of transportation which was $2.75 per cu. yd.

The cost of a masonry aqueduct consisting of masonry piers, arches and spandrels, was as follows:

To lay masonry:	Per day.
1 mason	$2.25
2 tenders, at $1	2.00
½ stone cutter, at $2.40	1.20
Total, 5.9 cu. yds. laid, at $0.92 per cu. yd.	$5.45

To lay arch masonry:	Per day.
1 mason	$ 2.25
2 tenders	2.00
1 stone cutter	2.50
Total, 8.95 cu. yds. laid at $0.76 per cu. yd.	$ 6.75

To lay spandrel masonry:	Per day.
1 mason	$ 2.25
2 tenders	2.00
1⅔ stone cutters	4.00
Total, 8.26 cu. yds. laid at $1 per cu. yd.	$ 8.25

The total cost of aqueduct masonry, per cubic yard, excluding the cost of laying just given, was as follows:

	Per cu. yd.
Quarrying	$ 2.25
Transportation	2.00
Cutting	2.25
Mortar	1.00
Machinery	0.25
Total, not including laying	$ 7.75

Approximately $0.90 per cu. yd. should be added to this $7.75 to include cost of laying the masonry.

Cost of Sweetwater Dam.—James D. Schuyler gives the following data on the Sweetwater Dam, California: The dam is 46 ft. thick at the base, 12 ft. at the top, and 90 ft. high. It is built as an arch with a radius of 222 ft. on line of face at the top. The stone was a metamorphic (or igneous?) rock with no well-defined cleavage, breaking out in irregular masses. Its weight ranged from 175 to 200 lbs. per cu. ft. And the average weight of the masonry was estimated to be 164 lbs. per cu. ft. The mortar was a 1 : 3, proportioned by barrels, mixed in a Ransome mixer. The mixer was given 3 or 4 turns after charging it with sand and cement, then the water was admitted during the next 3 or 4 revolutions; 8 to 10 revolutions made a thorough mixture, requiring 2 to 3 mins. A tramway for delivering the mortar was carried around the face of the dam, on a bracket trestle held by bolts driven into

holes drilled in the face of the dam masonry. A grade of 3 ft. in 40 at the end of the tramway next to the mixer was sufficient to give the mortar car an impetus that would carry it to the farthest end of the dam. By using this mechanical mixer and tramway a force of 5 men and a horse did the work formerly done by 4 mortar mixers and 14 hod carriers. The box of mortar was lifted from the car by a derrick and delivered to the masons.

The stone was quarried from a cliff 100 ft. high situated 800 ft. below the dam. It was hauled in wagons rigged with platforms on a level with the rear wheels. The quarry derricks were simple shear-legs, slightly inclined. All stones smaller than 500 lbs. were loaded on stone boats 4 ft. square, made of 3-in. plank with a bottom of boiler plate and provided with chains at the corners. The shear-leg derricks were used to hoist the stone boats and deposit their loads on the wagons. Stone boats cost $30 each, and several sets of them were worn out on the job. A single stone, weighing 3 tons or more, was readily lifted by the shear-legs, and lowered upon a wagon driven underneath. All hoisting was done by horse power. Four derricks were used on the dam, masts being 30 to 38 ft. long, and booms 26 to 32 ft. A fifth derrick, with a 50-ft. mast and a 45-ft. boom, proved far more efficient than the others. The work was completed Apr. 7, 1888, after 16 mos.

The masonry was rubble throughout, amounting to 20,507 cu. yds., of which 19,269 cu. yds. were in the dam proper; 0.86 bbl. of cement was used per cubic yard of masonry.

The cost of the dam was as follows:

17,562 bbls. cement	$ 63,111
Hauling cement	8,614
Lumber	2,408
Iron work	4,916
Powder and miscellaneous supplies	3,230
Pipes, gates, etc.	5,152
Plant, tools, etc.	6,237
Total for materials and plant	$ 93,668
Labor, common and skilled	$ 93,591
Foremen	6,866
Teams	19,696
Engineering	10,555
Clerical work	654
Earthwork (by contract)	7,666
Miscellaneous expenses	1,377
Total for labor	$140,405
Total for materials, etc.	93,668
Grand total	$234,073

Common laborers were paid $2 to $2.50 a day; masons, $4 to $5; carpenters, $3.50 to $4; blacksmiths, $4; teams with drivers, $5; machinists, $7 to $8; foremen, 4 to $6. Workmen were scarce and independent on account of the "boom" in California. The work cost 20 to 25% more than it would have cost under normal conditions.

The itemized cost of 11,322 cu. yds. of the masonry laid from May 1 to Dec. 31, 1887, was as follows per cubic yard:

	Per cu. yd.	Percentage of total.
Quarrying stone (labor)	$ 0.425	4.829
Loading stone	0.523	5.933
Hauling stone	0.420	4.758
Hoisting stone	0.577	6.550
Loading and hauling sand	0.345	3.915
Cement, at $4.20 per bbl	3.427	38.900
Mixing and delivering mortar	0.239	2.710
Masons	0.797	9.050
Helpers	0.186	2.109
Excavating foundations	0.303	3.444
Making and repairing roads	0.118	1.336
Blacksmithing (labor)	0.163	1.854
Carpentry	0.097	1.104
Rope	0.104	1.186
Tools	0.046	.524
Steel	0.014	.155
Blacksmith coal	0.009	.109
Blocks and sheaves	0.011	.13[illegible]
Powder	0.086	.974
Lumber	0.195	2.220
Wetting masonry	0.048	0.542
Foremen	0.332	3.774
Engineering and superintendence	0.343	3.891
Total	$ 8.808	100.000

Cost of a Granite Dam, Cheyenne, Wyo.—Mr. A. J. Wiley gives the following data on a dam for the Granite Springs Reservoir, Cheyenne. The work was done by contract, April 20, 1903, to June 21, 1904. From Nov. 20, 1903, to April 11, 1904, work was closed down on account of cold weather. The extreme height of the dam is 96 ft., and the length of the crest is 410 ft.; the thickness at the base is 56 ft., and on the top it is 10 ft. It contains 14,222 cu. yds. of granite rubble masonry laid in 1:4 Portland mortar, except for the face of stones where 1:3 mortar was used. The mortar constituted 35.2% of the dam; and 0.61 bbl. cement was used per cubic yard of masonry.

The mortar was mixed with a Smith mixer, in batches of ½ cu. yd., and the mixer output was 6 cu. yds. per hr. The mortar was dumped into buckets and carried on cars running on a trestle built along the up-stream face of the dam. Derricks on top of the dam hoisted the mortar buckets.

The stone was a gabbro, quarried about 100 ft. below the dam. It was devoid of cleavage and was blasted out in large masses from an open face 20 to 40 ft. high. The drilling was done by hand. For each cubic yard of rock there were used 0.35 lb. of dynamite and 1.05 lbs. of black powder. The stones averaged 2 cu. yds., but pieces containing 5 cu. yds. were used.

Rocks breaking smaller than 3 cu. yds. were used as they were blasted out of the quarry, and larger masses were split up by plug and feather into roughly rectangular shapes. The best shaped stones were used for face stones, the ordinary rough rocks were used in the body of the dam, and the smaller pieces made the spalls. The rock was taken from the quarry by a guyed derrick with 40-ft. boom, and loaded upon platform cars. The track was laid upon such a grade that the loaded cars ran alone and the empties were

pushed back by hand. The trestle which carried the track was supported by the steps on the down-stream side of the dam. Upon the top of the dam were located two guyed derricks with 40-ft. booms similar to the quarry derrick. Each of the three derricks was operated by a 10-ton hoisting engine located in an engine house near the south end of the dam. The derricks on top of the dam took the rock from the cars on the lower side of the dam and set them in the masonry. They also took the mortar buckets from the cars on the up-stream side of the dam and dumped them where needed on top of the dam.

Spalls were brought upon the dam in skips, holding about a cubic yard each, and kept in the skips until used. The mortar was usually dumped in half-yard batches in a convenient depression of the masonry, and was distributed with long-handled, round-pointed shovels.

The up-stream face was laid with the joints in the true plane of the face. No objection was made to having the convexity of a stone project beyond this plane, but no stones with concave faces were permitted in the face of the dam. The upper 20 ft. of the down-stream face were laid in the same manner, but the rest of the down-stream face was laid in rough steps with half the step inside and half outside the theoretical plane of this face. The stones in both these faces were laid to break joint and were well bonded into the body of the dam. In the body of the dam but little attention was paid to the bond of the work, the irregular stones insuring this without effort, but every precaution was taken to insure the filling of voids. To this end the mortar was used very wet, even sloppy, and the chief rule observed was that there should first be placed a large excess of mortar of which the largest possible percentage was to be displaced by rock. In setting the large rock, a bed was prepared with spalls and mortar, and then a considerable excess of mortar was placed on the bed. The rock was then slowly lowered and settled on the bed by working it with bars. The excess mortar would ooze from under the rock which would then float upon an even layer of mortar, filling all the spaces under it. During this operation the inspector, either standing upon the rock or having his hand upon it, can tell if the rock is riding or rocking, and, if necessary, has the rock raised and the bed readjusted. The large rocks were set as close as possible to each other without being in contact, the intervening spaces being filled with mortar and spalls. In this work the masons were not permitted to sandwich the spalls between layers of mortar, but were required first to fill the space with wet mortar in which the spalls were submerged, displacing as much as possible of the mortar. While it was the intention to have the masonry brought up in horizontal benches extending the full length of the dam, the exigencies of the work prevented this and the middle portion of the dam was completed first, stepping off toward each end. The average rate of progress was 60 cu. yds. of masonry per day of ten hours. The best monthly rate was 2,370 cu. yds. during July,

1903, averaging 83 cu. yds. for a ten-hour day, or 41.5 yds. of masonry per ten-hour day for a single derrick, including the time lost in moving and resetting derricks. During this month the average daily force employed was as follows: In the quarry, 21.3 men, 1⅓ engine runners, and one derrick; in screening and hauling sand, 3.2 teams with drivers, and 3.2 men; in mixing and delivering mortar, 3 men; in laying masonry, 3.5 masons, 6.5 helpers, 2⅔ engine runners, and 2 derricks.

The following were the average wages paid per 10-hr. day: Quarrymen, $2.50; masons, $5.00; masons' helpers, $2.25 to $2.50; engine runners, $3.00; common labor, $2.25.

The actual cost of the masonry was as follows:

	Per cu. yd.
0.652 cu. yd. solid rock, $1.96	$ 1.28
0.348 cu. yd. mortar (not incl. cement), at $1.93.	0.67
0.613 bbl. cement, at $3.58, delivered	2.19
Labor laying 1 cu. yd	1.11
Total	$ 5.25

The solid rock was quarried and delivered for $1.96 per cu. yd. (solid), itemized as follows:

Quarrying and Delivering:	Per cu. yd. (solid).
Common labor	$ 1.06
Engine runners	0.14
Coal, $6 per ton	0.08
Blacksmithing	0.13
Steel	0.04
Explosives	0.15
Interest and dep. on plant ($1,644)	0.18
General expenses	0.18
Total per cu. yd. (solid)	$ 1.96

This is equivalent to $1.28 per cu. yd. measured in the dam.

The cost of securing the sand and mixing the mortar was as follows per cu. yd. of mortar:

	Per cu. yd.
Labor digging and hauling (teams) sand	$ 1.10
Blacksmithing, sand pit	0.13
General expense, sand pit	0.19
Labor mixing and delivering	0.30
Fuel, $6 per ton	0.04
Interest and depreciation on plant ($620)	0.12
General expense	0.05
Total per cu. yd. mortar	$ 1.93

The cost of laying the masonry was as follows per cu. yd. of masonry:

	Per cu. yd
Labor, masons and helpers	$ 0.50
Engine runners	0.18
Fuel, $6 per ton	0.10
Blacksmithing	0.02
Interest and depreciation on plant ($3,000)	0.22
General expense	0.09
Total	$ 1.11

The interest and depreciation on the plant was assumed to be

50% of the first cost of the plant. The fuel was estimated on the basis of 5 lbs. of coal per horse-power hour of actual working time for the nominal horse-power of the engines. As a matter of fact, a large amount of cord wood was used instead of coal.

Cost of Masonry, New Croton Dam.—This dam was built of gneiss (a granitic rock), and the average cost to the contractor during the years 1897 to 1905 was about as follows for the rubble masonry:

	Per cu. yd.
0.95 bbl. cement, at $1.85	$1.75
Quarrying ⅔ cu. yd. solid stone, at $1.50	1.00
Sand, ⅓ cu. yd., at $0.90	0.30
Labor laying masonry	0.90
Pumping	0.10
Plant, roads, etc.	0.60
General expense, 2% estimated	0.10
Total	$4.75

In quarrying about 25% of the rock was wasted.

In laying the masonry cableways were used for about half the yardage, and steel towers with derricks were used for the other half.

Some of the face stone was dressed. The rough pointing of 38,000 sq. ft. cost $0.60 per sq. ft. The 6-cut ax work on 84,000 sq. ft. cost $1.20 per sq. ft.

Cost of a Rubble Dam.—This dam was built in 1898 by contract, under the direction of Mr. George W. Rafter, across the Indian River, Hamilton County, N. Y. The main dam was 7 ft. wide on top, 47 ft. high, 33 ft. wide on bottom, and 400 ft. long. The face masonry was dressed to lay 1½-in. joints. The backing was large irregular rubble stones laid in beds of 1 : 3¼ mortar, and the vertical joints filled with 1 : 3¼ : 7½ concrete. No attempt was made to keep separate accounts of the face masonry and the backing, but it was estimated that 27% of the dam was mortar. The stone was a pink synetic granite, quarried 500 ft. from one end of the dam. There was no difficulty in quarrying regular blocks for the face. The sand was loaded upon a scow holding 30 cu. yds. and hauled 2 miles down the river. A foreman and 6 men, by using a windlass, rope and sail, handled the scow. They loaded and delivered 720 cu. yds. of sand and 180 cords of wood per month, at a cost of about $310. Wages of common laborers were $1 a day and board, and it is probable that the board cost $0.50 per man per day.

The plant to build the dam cost $10,340. The actual cost of the dam to the contractor was:

Labor clearing 35 miles of margins, 1,160 acres	$13,000
Hauling cement and supplies 22 miles	6,836
Freight, cement and supplies	960
Barn account (teams owned by contractor)	725
Stone, cement and other materials	18,830
Labor (not including clearing)	31,218
General expense	9,601

Interest	1,150
Insurance	1,235
Depreciation of plant, est. 33%	3,450
Total	$87,005

The "general expense" includes coffer-damming and pumping, erecting and wrecking the plant, etc. The time occupied in doing the work was 7 months.

In July and August, when the work was well under way, the cost of the masonry was very low, and averaged as follows:

	Per cu. yd.
Quarrying face stone (not incl. backing)	$0.35
Labor laying masonry	0.53
Labor pointing masonry	0.15
Mixing mortar and concrete, and crushing	0.20
Cement	2.00
Sand	0.15
General expense and superintendence	0.27
Total	$3.65

In addition to this there was the cost of quarrying the stone for the backing; but this stone was paid for as excavation, so it is not included above. During July and August this excavation cost 46 cts. per cu. yd.

It will be noted that the accounts were not well kept, for no statement is given of the proportion of backing to face stone. The quarrying of the face stone doubtless cost several dollars per cubic yard of the face stone, although it amounted to only $0.35 per cu. yd. when distributed over all the masonry. Nor is it stated what the dressing cost. From measurements on a drawing of the cross-section of the main dam, I estimate that it runs 29 cu. yds. of masonry per lin. ft., of which about 30% is face stone, if we allow a depth of 2½ ft. of face stone extending into the dam; but in the lower third of the dam, where there is great breadth, the face stone would not be more than 20% of the total masonry, and at the bottom only 15%. Hence if the work in July and August was in the lower part of the dam, as it doubtless was, we must multiply the $0.35, above given, by at least 5 to secure an approximate estimate of the cost of quarrying a cubic yard of face stone. Indeed, it is likely that the cost of face stone was more than 5 times $0.35 per cu. yd.

I have gone into these details for the purpose of showing how little value there often is in published cost records, because of the failure of engineers to keep their cost records properly. The wages of quarrymen and masons are not given.

Data on Laying Masonry With a Cableway.—Mr. Spencer Miller gives the following data on the use of cableways for laying masonry. The Basin Creek Dam for the water-works of Butte, Mont., is 120 ft. high and 300 ft. long, designed by Mr. Chester B. Davis. A cableway 892 ft. between towers, spanned the dam and the quarry. No derricks were used on the dam, for, by using a snubbing post and a horse, the stones could be swung where desired.

In 16 days a gang of 86 men quarried and laid 1,430 cu. yds. of masonry. This gang included 6 masons, quarrymen, firemen and all laborers about the dam and camp. These six masons averaged 15 cu. yds. of masonry each per day.

At Rochester, N. Y., two cableways, side by side and 60 ft. apart, were used to erect a stone arch bridge 630 ft. long and towers 50 ft. high. A 30-hp., 8¼ × 10-in., engine was used for each cableway. Stones were laid between the cableways by hitching the hoisting lines of both cableways to the same stone. To lay the masonry piers a frame was used which straddled the piers and on top of which a traveler was used to place the stone as fast as it was delivered by the cableway. After a pier was completed the framework and traveler were lifted by the cableways to the site of the next pier, in less than 10 minutes. The centers for the arches were lifted into place by the cableways. This highway bridge contained 2,200 cu. yds. of masonry in piers and arches, 2,278 cu. yds. arch sheeting, 2,660 cu. yds. concrete spandrel backing, and 310,000 lbs. of iron work; 350 M of lumber were used in the centers.

Cost of Masonry and Timber Crib Dam.—Mr. Maurice S. Parker gives data on the Black Eagle Falls Dam, Missouri River, Great Falls, Mont. The work was done by day labor (Apr. 15, 1890, to Jan. 6, 1891) under Mr. Parker's supervision, wages being as follows: Common labor, $2; stone masons, $4; carpenters, $3.50; quarrymen, $2.25; stone cutters, $4.50; quarry foremen, $3.50; mason foremen, $5; stone cutter foremen, $5; carpenter foremen, $5.

The stone was a red sandstone weighing 160 to 170 lbs. (some specimens 178 lbs.) per cu. ft., and was quarried from the bed of the river, the average haul being 500 ft. on push cars. The stone occurs in vertical strata 1 to 4 ft. thick, the bedding planes making an angle of 45° with the current. Timber was delivered near the gate chambers. Cement used was Milwaukee and Buffalo mixed 1:2. Portland cement was used in freezing weather and gave perfect satisfaction, being now as hard as stone. The following table gives the cost of the labor in construction, including all handling of materials after unloading from cars:

	Cost of labor.
4,600 cu. yds. first class rubble, at $6.56	$30,438
1,500 cu. yds. cut stone masonry, at $16.40	24,600
5,000 cu. yds. dry stone filling in cribs, at $2.10	10,500
10,000 cu. yds. excav., half rock, half earth, at $1.07	10,700
1,200 M timber in cribs, at $10.85	13,020
100 M timber in gates and chambers, at $33.72	3,372
Engineering expenses, 12 mos	5,900
Total cost of labor	$98,530

The expense of false work of all kinds, such as cofferdams, tramways, etc., amounted to 5% of the total cost and is divided proportionately between the classes of work above given. The cost of labor on timber in gates and chambers includes the cost of placing all irons and gearing. The total cost of the dam was $175,000.

including materials, labor and salaries. About 20% of the rubble was broken range faced. The cut-stone masonry was laid with close beds and joints.

The minimum flow of the river is 4,000 cu. ft. per sec. The average depth of water was 2 ft. when work was begun, but it was very swift as the rapids at the site of the dam had a fall of 2 ft. in a 100 ft. During June floods the depth was 6 ft. The crib dam is 745 ft. long, and the canal and gates occupy an additional width of 95 ft. The average height of the dam is 14 ft., resting on a ledge of sandstone. The longitudinal timbers of the crib are spaced 8 ft. c. to. c. The bottom timbers were cut to fit the rock, bedded in cement mortar and drift bolted to plugs of wood driven into holes drilled in the ledge rock.

The work was begun on the north side of the river, a sheer dam being first built to divert the stream from the dam site. This sheer dam consisted of wooden horses placed 8 ft. apart, with stringers of 4-in. plank. A facing of 2-in. tongue and grooved planks was placed on the up-stream legs of the horses, and a row of sand-filled bags placed at the toe of the planks. There was a little leakage, and the leakage water was diverted by a second row of sand bags parallel with the first row, and a short distance down stream. This sheer dam withstood a flood 6 ft. deep.

On the south side of the river, which was deeper and swifter, it was necessary to sink small triangular stone-filled cribs to support the wooden horses for the sheer dam. These cribs were of 4-in. plank with 6-in. posts, each holding 1 cu. yd. of stone, and were placed 8 ft. apart, each crib supporting a horse. At times the depth of water against this sheer dam was 15 ft., but the leakage was easily cleared with hand pumps.

To close the long gap between the two ends of the dam, wooden horses were placed 8 ft. apart with a foot walk of 4-in. plank on top, and heavy timbers to hold the horses down. From this temporary bridge a second tier of horse bents was placed (8 ft. c. to c.) on the up-stream side, connected with 4-in. stringers and sheeted with 4-in. plank. The dam was intended to break the force of the current, which it did admirably. The leakage was taken care of in sections by small sheer dams built of matched plank, and by the use of sand bags. Every 48 ft., an opening of 14 ft. was left in the crib dam which was used as a temporary sluiceway when the cofferdam was removed. These gaps were subsequently closed with planks, and the cribwork with its stone filling built in.

Cost of Laying Masonry, Dunning's Dam.—Mr. E. Sherman Gould is authority for the following data on The Dunning's Dam near Scranton, Pa. The dam is masonry on a concrete foundation, built by contract. The stone for the masonry was a conglomerate laid in swimming beds of mortar. On one occasion one foreman, 8 masons and about 9 helpers laid nearly 500 cu. yds. of rubble in 76 hrs., using a double drum engine and derrick. This is equivalent to 8.2 cu. yds. per 10-hr. day per mason. On another occasion, another foreman, 7 masons and 8 or 9 helpers laid 375 cu. yds.

in 7 days, or 7.6 cu. yds. per mason per day. This was very rapid work in both cases.

Cost of Quarrying and Laying a Limestone Wall.—Mr. James W. Beardsley is authority for the following data on the cost of quarrying and laying limestone for retaining walls on the Chicago Canal. The contractors selected parts of the canal where the limestone occurred in strata and were uniform, so that the beds of the stone quarried required no dressing. The stone was laid in courses averaging about 15 ins. thick, the better stone being selected for the face of the wall. Guy derricks having a capacity of 6 to 10 tons, boom 40 to 60 ft. long, operated by a hoisting engine, were used for loading the stone. Black powder was used to shake up the ledges and the stone was then barred and wedged out. The cost per cu. yd. is the average of 93,500 cu. yds., measured in retaining walls. The mortar was only 13¼% of the wall, indicating an unusually even bedded stone that squared up well. The cost does not include general superintendence, installation of plant, plant rental, powder, material for repairs, and cost arising from delays.

Mr. Beardsley has evidently divided the number of working days credited to each class of men by the total number of days worked on the job, which results in giving fractions of days labor in the following typical force:

	Per cu. yd. masonry.
Quarry force:	
1 foreman, at $3.50	$0.078
2.11 derrickmen, at $1.50	0.075
8.42 quarrymen, at $1.65	0.312
1.10 enginemen, at $2.25	0.052
2.28 laborers, at $1.50	0.080
0.33 waterboy, at $1.00	0.007
0.27 blacksmith, at $2.50	0.013
0.18 blacksmith's help, at $1.75	0.007
0.36 drill runner, at $2.00	0.023
0.07 drill helper, at $1.50	0.002
0.04 watchman, at $1.50	0.001
0.29 team, at $3.50	0.028
1.12 derricks, at $1.25	0.040
0.36 drill, at $1.25	0.015
Total quarry force	$0.733
Wall force:	
1 foreman, at $4.25	$0.113
4.20 masons, at $3.50	0.354
1.46 masons' helpers, at $1.50	0.058
1.81 mortar mixers, at $1.50	0.073
0.66 mortar laborer, at $1.50	0.027
1.82 hod carriers, at $1.50	0.073
1.77 derrickmen, at $1.50	0.071
1 engineman, at $2.25	0.054
1.62 laborers, at $1.50	0.065
0.45 waterboy, at $1.00	0.009
0.86 team, at $3.50	0.078
0.20 carpenters, etc., at $2.50	0.010
1.59 derricks, at $1.50	0.042
Total wall force	$1.027

This wall force of 16 men laid 87 cu. yds. per 10-hr. day, each mason averaging 8.8 cu. yds. The rates for derricks, etc., apply to the cost of fuel, at $2 a ton. The wall derricks were stiff-legs, having booms 40 ft. long, and were moved on a track parallel with the wall.

Work was done between Sept., 1894, and Oct., 1896, with a plant having a total value of $30,200. The total cost of the masonry was as follows:

Quarry force	$0.73
Wall force	1.03
Sand, at $1.35 per cu. yd	0.13
Cement, at 60 cts. per bbl	0.24
Total	$2.13

Cost of a Masonry Wall, Including Excavation.*—The work was done in September, 1896, and consisted of the construction of a retaining wall at the round house of the Detroit, Lansing and Northern R. R., at Grand Rapids, Mich. The contractor furnished the labor only, the material being furnished by the railroad com-

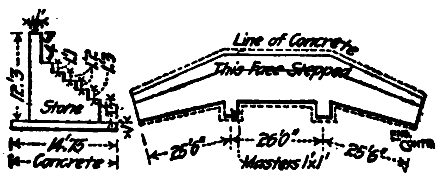


Fig. 1. Masonry Abutment.

pany. The wall was built in the shape shown in Fig. 1, as it was desired to utilize it as the foundation for a future extension of the round house.

Excavation.—The excavation was nearly all stiff clay with stone and small boulders, thus making hard digging. Almost all of the excavated matter was handled twice, cast out on the ground and then loaded on flat cars. The time given for excavation includes, perhaps, six or eight dollars' worth of time spent in moving cars. In all of the work the contractor was considered as a foreman and was allowed 40 cents per hour for the time he himself actually worked. In all of the cases the foremen hours are for the hours during which actual work was done by them. That is to say, the foreman not only acted as overseer, but also did actual work, excavating, laying stone, etc.

The cost of the excavation work was as follows:

Foreman, 33 hours, at 40 cts. per hour	$13.20
Foreman, 104 hours, at 22½ cts. per hour	23.40
Laborer, 285 hours, at 12½ cts. per hour	35.63
Total	$72.23

*Engineering-Contracting, May 30, 1906.

A total of 168.1 cubic yards was excavated at a cost of $0.43 per yard. The contract price at which the work was let was $0.25.

Back Filling.—In back filling the earth was wheeled from the flat cars and placed back of the wall. A small amount of earth was cast in directly from the bank. The cost of this work was as follows:

Foreman, 4 hours, at 40 cts. per hour.........	$1.60
Foreman, 11 hours, at 22½ cts. per hour.........	2.48
Laborer, 52 hours, at 12½ cts. per hour.........	6.50
Total	$10.58

The back filling amounted to 63 4/10 cu. yds., and this was done at a cost of $0.17 per cubic yard. The contract price was $0.25 per cubic yard.

Concrete.—The proportions for the concrete were 1:2½:5, Akron (natural) cement being used. All conditions were favorable for fair work. It was found that 1 cu. yd. of concrete was equivalent to 29.8 cu. ft. of material, composed of 3.6 cu. ft. cement (1 1/10 bbl.), 8.4 cu. ft. sand (2 7/10 bbl.) and 17.8 cu. ft. broken stone (5½ bbl.).

The cost of 15½ cu. yds. of concrete was as follows:

Foreman, 14 hours, at 40 cts. per hour..........	$ 5.60
Foreman, 20 hours, at 22½ cts. per hour.......	4.50
Laborer, 49 hours, at 12½ cts. per hour.........	6.11
Mason, 2 hours, at 35 cts. per hour............	.70
Total	$16.91

A total of 15½ cu. yds. concrete was prepared at a cost of $1.09 per cubic yard; the contract price was $1.00 per cubic yard.

Stone Laying.—In the stone laying, Petoskey limestone was used. The limestone weighed, according to car weights, 5.9 tons per cord, equal to 93 lbs. per cubic foot of piled stone. Conditions were fair for good work. It was here found that 1 cu. yd. rubble masonry required 0.25 cord stone, 0.22 cu. yds. sand and 0.54 bbl. cement.

Akron (natural) cement, one barrel containing 3½ cu. ft., was used and the mortar was mixed in the proportions of 1:3. In the force account given below the foreman laid stone, and all other foreman hours are for actual work.

The cost of laying the 82.2 cu. yds. of rubble is shown in the following table:

Foreman, 78 hours, at 40 cts. per hour..........	$31.20
Foreman, 80 hours, at 22½ cts. per hour......	18.11
Mason, 41 hours, at 35 cts. per hour............	14.52
Laborer, 168 hours, at 12½ cts. per hour......	21.00
Total	$84.83

A total of 82.2 cu. yds. of wall was built, the labor cost per cubic yard being $1.03; the contract price was at $1.25 per cubic yard.

If the full cost of the plant is charged to the work, another 32 cts. per cu. yd. must be added for plant.

The mortar was mixed 1 : 1, and Louisville (natural) cement was used, each bag being called 2 cu. ft.

The wall averaged 24 ft. high, and was 4 ft. wide for the upper 8 ft., then it widened to 12 ft. at the base. It was laid in courses 12 to 18 ins. thick.

Cost of Laying Bridge Pier Masonry.—Mr. Gustave Kaufman gives the following data on the abutments and piers of a highway bridge across the Ohio River at Cincinnati. The total length of the bridge is 2,966 ft., with a 24-ft. roadway and two 7-ft. sidewalks. There are two abutments, nine masonry piers, of which four piers are founded on limestone, and five on piles. There are 28 pedestals for the steel viaduct approaches. The center span of the bridge has a clear height of 102 ft. above low water. Work on the substructure was begun May 1, 1890, and floods caused many delays, so that the bridge was not opened till Aug., 1891.

Louisville cement was used throughout, except Portland cement for pointing. Piers Nos. 1, 2, 3 and 9 are Ohio River freestone, with a backing of freestone. Where pile foundations were used, the heads of piles were imbedded in 3 to 4½ ft. of concrete foundation. Piers 4 to 8, inclusive, are of Berea sandstone with a backing, or hearting, of concrete, up to the belt course, above which the masonry is Ohio River freestone entirely. The dimensions of the piers are shown in Table I.

TABLE I.—DIMENSIONS OHIO RIVER PIERS.

Pier. No.	Size Under Coping. Feet.	Height Over All. Feet.	Size at Base of Shaft. Feet.	Cubic Yards Masonry.	Remarks.
1	5 × 30	26.2	6.4 × 31.4	146.2	Square shaft.
2	5 × 30	39.4	7.6 × 32.6	271.7	"
3	6 × 30	47.0	9.1 × 33.1	393.9	Circular shaft.
4	9 × 34	74.0	13.8 × 49.5	1,432.9	"
5	10 × 34	112.8	17.3 × 53.7	2,357.6	"
6	10 × 34	104.1	17.8 × 54.2	2,475.6	"
7	9 × 34	93.4	16.0 × 51.8	1,974.1	"
8	7 × 32	87.1	13.4 × 46.8	1,393.3	"
9	7 × 32	37.3	9.6 × 34.6	330.1	Square shaft.

Note.—Pier No. 3, height includes caisson. The coping of all piers was Bedford oolitic limestone 18 ins. thick, except for piers 5 and 6 which had a 24-in. coping. There were 2,173 cu. yds. of masonry in the ramps on both sides of the river.

The masonry was laid with the help of derrick scows, and the cost of laying the 280 cu. yds. above the starling course was $1.25 per cu. yd., including the cost of sand and cement. The cost of laying the sub-coping and coping was $1.45 per cu. yd., including sand and cement. The cost of laying masonry and concrete, courses 5 to 21, was $1.30 per cu. yd., including sand and cement. These costs do not include cofferdams. Wages were as follows, per 10-hr. day: Common labor, $1.50; masons, $3.25; stone cutters, $3.50; enginemen, $2.00; foreman, $4.00.

The face stones were laid alternate headers and stretchers, stones being not less than 3½ ft. long, dressed to ⅜-in. bed joints and

⅝-in. vertical joints for at least 12 ins. back of the face. The width of each stone was 1¼ times the depth of the course.

The cost of laying Pier 5 was $0.73 per cu. yd., courses 1 to 37; and $1.11 per cu. yd., courses 38 to 54; and $1.10 per cu. yd., courses 55 to 56; the cost of sand and cement is included in all cases. See Tables II and III.

Cost of Sodom Dam.—Mr. Walter McCulloch gives the following data on the Sodom Dam, on the east branch of the Croton River, N. Y. The dam is 500 ft. long at the coping, 240 ft. long at top of foundation, 53 ft. thick at foundation, 12 ft. thick under coping, and 78 ft. high above ground line. Work was begun Feb. 22, 1888, and completed Oct. 29, 1892. The contractor paid laborers $1.25 a day, and masons, $3.50. There were 35,887 cu. yds. of masonry of all classes. Of this 23,600 cu. yds. were rubble laid in 1:2 Portland mortar, 6,300 cu. yds. rubble in 1 : 3 mortar, 780 cu. yds. of granite dimension stone masonry, 4,300 cu. yds. limestone face masonry, and 530 cu. yds. of brick masonry. The face masonry and brickwork were laid in 1 : 2 Portland mortar. The rubble was quarried 1¼ miles from the dam and hauled on double team trucks carrying 1 to 1½ cu yds. per load, making 6 to 8 trips a day. The rock was a hard, close-grained gneiss of irregular cleavage. The face stones (4,300 cu. yds.) were quarried at a limestone quarry 7 miles away and delivered on cars of the N. Y. & N. E. R. R. These stones were cut for 30-in. courses, stretchers being 3½ ft. long, and headers 4 ft. long. Dimension stones (780 cu. yds.) were granite from Wilmington, Del. Cement cost from $2.31 to $2.51 per bbl. The cost of the rubble stone delivered on the work from the quarry was $1.97 per cu. yd., including 5 cts. quarry royalty. Rubble stone and spalls from the excavation waste banks cost $0.67 per cu. yd. The average cost of rubble stone was $1.26. The actual cost of rubble masonry in 1:2 mortar was $4.45 per cu. yd. The actual cost of limestone for face work was $9.75 per cu. yd., including 15 cts. quarry royalty, but not including laying and mortar. The cost of dimension granite on the work, including dressing, was $30.08 per cu. yd. The cost of the coffer-damming and other work is not given.

A cableway spanned the dam, 2-in. cable, 7 lbs. per ft., 667-ft. span, sag 25 ft. under 10-ton load. The cableway plant cost $3,800. After four months' use the cable, under a load of only 6 tons, broke 50 ft. from one tower, at a place where stone and cement skips were taken up. A new cable was installed, the towers raised 10 ft. so as to give it more sag, and it served till the end of the work. The cableway anchors were oak deadmen, 2 ft. diameter by 10 ft. long, in trenches in rock 6 ft. deep. The masonry was laid with fixed derricks and with a traveling derrick on a 30-ft. trestle running upon a track of 36-ft. gage. The best month's work was 3,000 cu. yds. laid with 12 masons and three derricks; the average progress was 1,700 cu. yds. per month. The Giant Portland cement came in duck bags of 100 lbs. each (93 lbs. net), four to the barrel. The Union natural cement came in 100-lb. bags (96 lbs. net), three

TABLE II. PIER No. 4—OHIO RIVER.

No. of course.	Size of course out to out, ft.	Thickness of stone, ins.	Cu. yds. face masonry.	Cu. yds. backing.	Cu. yds. mortar in all joints.	Face work per cent of whole.	Bbls. cement per cu. yd. face.	Bbls. cement per cu. yd. backing.	Remarks.
1	23.2 × 59.2	19	30.9	46.1	1.45	40%	.26	1.70	Footings.
2	21.4 × 57.3	19	29.4	39.7	1.05	43%	.37	1.64	"
3	19.4 × 55.2	32	53.3	47.4	1.30	53%	.32	1.52	"
4	16.4 × 52.2	28	32.4	39.0	.93	45%	.37	1.79	"
5	13.7 × 49.4	26	28.4	22.7	.88	58%	.35	1.68	Masonry (with concrete backing), having semi-circular ends.
6 to 11	Averages =	26	27.8	20.6	.86	58%	.26	1.80	
12	12.4 × 48.1	25	26.4	17.7	.84	60%	.26	1.81	
13 to 20	Averages =	24½	24.9	15.0	.80	63%	.33	1.70	
21	10.7 × 46.4	24	24.1	11.0	.80	69%	.29	1.63	
22	11.8 × 47.5	22	23.1	12.7	6.20	65%	.42	Included with face work.	Starting course.
23 to 24	Averages =	17	15.1	9.5	4.80	62%	.50		Hood courses.
25	10.5 × 35.5	18	10.0	12.1	8.40	45%	.53		Masonry with rubble backing, courses 22 to 38.
26 to 36	Averages =	16½	11.0	6.5	3.14	63%	.59		
37	9.0 × 34.0	15	8.9	5.8	2.95	60%	.47		
38	10.0 × 35.0	18	13.8	6.2	2.99	69%	.50		Sub-coping.
39	11.0 × 36.0	18	21.8	....	.72	100%	.50		Coping.

NOTE.—Cement per cu. yd. face work, courses 1 to 21 = 0.30 bbls.
Cement per cu. yd. concrete, courses 1 to 21 = 1.71 bbls.
Cement per cu. yd. masonry, courses 22 to 39 = 0.56 bbls.

All face stones had a width 1¼ times their thickness, and below the starting course were laid with Flemish bond, alternate headers and stretchers. Mortar was 1 to 2; concrete was 1 : 2 : 4, broken stone; Louisville cement throughout.

TABLE III. PIER NO 5—OHIO RIVER.

No. of course.	Size of course out to out, ft.	Thickness of stone, ins.	Cu. yds. face masonry	Cu. yds. backing.	Cu. yds mortar in bed joints.	Face work, percentage of whole.	Remarks.
1	19.5 × 55.5	27	33.3	52.6	1.62	31%	Footing.
2 to 3	19.0 × 55.0	26	30.4	49.5	1.54	38%	"
4 to 9	Averages =	25	28.9	35.3	1.28	45%	Semi-circular ends.
10	16.2 × 52.5	24	26.0	32.9	1.22	44%	"
11 to 21	Averages =	24½	26.8	28.6	1.13	48%	"
22	14.1 × 50.5	24	25.2	24.4	1.04	51%	"
23 to 32	Averages =	21¼	21.7	19.3	.96	53%	"
33	12.4 × 48.7	21¾	22.3	16.4	.88	59%	"
34	13.3 × 49.6	21¾	23.3	17.5	.86	57%	Starting course.
35 to 37	Averages =	17	16.5	10.2	.78	62%	Hood courses
38 to 44	Averages =	16	13.5	7.2	.63	65%	Rectangular ends
45	11.1 × 35.1	16	12.7	6.4	.60	66%	"
46 to 53	Averages =	16	12.6	5.4	.57	70%	"
54	10.1 × 34.0	14	10.4	4.3	.53	70%	"
55	11.0 × 35.0	24	20.6	7.9	.53	72%	Sub-coping.
56	12.0 × 36.0	24	32.0	....	.59	100%	Coping

NOTE.—Between courses 1 to 33 the Louisville cement used was .33 bbl. per cu. yd.; courses 34 to 54 used .30 bbl. per cu. yd.; courses 55 and 56 used .35 bbl. per cu. yd.

Percentage of face work, courses 1 to 33 was 46.4%.
Percentage of face work, courses 34 to 54 was 65.8%.

Mortar was 1 to 2 throughout. There was one header to every three stretches, no face stone being less than 3½ ft. long, and dressed to ⅝ in. joints. No spaces wider than 6 ins. allowed between backing stones.

to the barrel. The sand and cement were mixed dry (3 turns with shovels) and delivered in boxes on the work where it was wet as needed. Rubble stones varied from 1 cu. ft. to 1 cu. yd. in size, and in placing them the beds of mortar were made very full and the stone thoroughly shaken till firm. Mortar was filled into the joints and then all the spalls that it would take were forced in. Care was taken not to build the rubble up in courses. In freezing weather, above 20°, hot brine (5 lbs. salt to 1 bbl. of water) and heated sand were used for the mortar. Salt and sand were sprinkled over the fresh mortar at night. In the spring the mortar laid in freezing weather could be scaled off 1/16 to ⅛ in. deep, but under this it was hard. In laying the foundation it was found that springs of water would wash the cement out of the concrete, so it proved better to lay beds of rubble made of small stones. The water could be led around the rubble and nursed from place to place till finally a small well, 2 ft. in diameter and 1 to 2 ft. deep, would be formed where the water boiled up. When the mortar about each little well had set, the water was bailed out, the well quickly filled with dry mortar, a bed of stiff wet mortar laid on top and covered with a large rubble stone. When the water was turned in behind this dam there were no leaks. This was in a large measure due to the use of rich mortar and careful work. No cracks developed.

Cost of Dams and Locks, Black Warrior River.—Mr. R. C. McCalla gives the following data relative to the cost of building masonry locks and dams on the Black Warrior River, Alabama. The work was done by hired labor for the government, in 1888 to 1895, at costs given in Table IV.

The stone is a sandstone quarried near the locks along the banks of the river and in the river bed. The stone for Lock and Dam No. 3 was quarried in a reef just above falls 7 ft. high. The quarry covered two acres, and was operated a depth of 12 to 18 ft. during low water, requiring only two 3-in. pulsometer pumps to keep it drained.

The face stone of locks Nos. 1, 2 and 3 were set in 1 : 3 Portland mortar (cement measured loose); the backing was partly set in mortar and partly in 1 : 3 : 5 concrete. Stiff-leg derricks were used to set the stones.

In October, 1891, 200 cu. yds. of backing and 600 cu. yds. of dimension stone were quarried for Lock No. 2, Black Warrior River, Tuskaloosa, Ala. The stone was a fine quality of blue sandstone quarried from the bed of the river at the falls, after diverting the water. The cost of quarrying these 800 cu. yds. was $1,598, or about $1 per cu. yd. for the backing and $2.33 per cu. yd. for the dimension stone. In this month 434 cu. yds. of dimension stone were cut by stonecutters at a cost of $6.83 per cu. yd. The masonry wall is 390½ ft. long, 8 to 14 ft. wide, and 34 ft. high, built in courses of ashlar 18 to 24 ins. thick, and about 50% cut stone. In October two gangs of masons, using two derricks, laid 1,563 cu. yds. of first-class masonry at a total cost of 92½ cts. per cu. yd., including the cost of screening sand, mixing mortar, operating steam

TABLE IV.—LOCKS ON BLACK WARRIOR RIVER.

	Unit.	Lock No. 1. Quantity.	Lock No. 1. Rate.	Lock No. 2. Quantity.	Lock No. 2. Rate.	Lock No. 3. Quantity.	Lock No. 3. Rate.
Stone quarried	cu. yds.	10,087	$3.41	11,282	$1.46	11,415	$1.66
Stone cutting	"	3,530	10.66	3,595	7.16	3,997	6.02
Laying masonry*	"	10,087	2.53	11,282	1.89	11,415	1.81
Earth excavation	"	10,809	0.28	6,876	0.24	3,529	0.26
Rock excavation	"	3,778	1.33	941	1.06	2,500	1.00
Earth filling	"	4,500	0.25	6,552	0.21	7,496	0.29
Rock filling	"	2,500	0.50	....	....	....	....
Paving, 12 ins. thick	sq. yds.	6,774		8,367	0.22	7,036	0.14
Turfing	"	3,132	....	1,021			
Gates and valves	....	....	12,010.00	....	9,698.00	....	9,919.00
Cofferdam and pumping	....	....	8,556.00	....	2,402.00	....	....
Handling and hauling stone	....	....	20,273.00	....	10,003.00	....	8,510.00
Boats and buildings	....	....	4,518.00	....	3,442.00	....	3,445.00
Track and roads	....	....	10,882.00	....	9,867.00	....	2,023.00
Tools and plant	....	....	28,535.00	....	22,513.00	....	17,852.00
Incidentals	....	....	6,771.00	....	5,841.00	....	5,713.00
Engineering and supt.	....	....	19,405.00	....	13,841.00	....	13,892.00
Total	....	....	$221,079	....	$146,881	....	$131,561
Cost per cu. yd. masonry†	....	....	....	....	....	....	$9.93

* Including cost of cement.

† This does not include earth and rock excavation, earth and rock filling and turfing, gates and valves.

TABLE V.—COST OF ROCK-FILL DAMS, BLACK WARRIOR RIVER.

		Dam No. 1.		Dam No. 2.		Dam No. 3.	
	Unit.	Quantity.	Rate.	Quantity.	Rate.	Quantity.	Rate.
Lumber and iron	Ft. B. M.	36,238	$27.89	53,556	$15.89	93,759	$13.59
Carpenter work	"	36,238	9.28	53,556	7.13	93,759	7.36
Stone quarried	cu. yds.	1,467	3.41	3,646	0.92	6,130	0.68
Stone dressed roughly	"	360	2.94	373	1.69	898	1.17
Laying masonry	"	1,467	0.85	3,646	0.51	6,130	0.31
Earth excavation	"	329	0.18	360	0.13	....	....
Filling above dam	"	502	0.85	607	0.66	1,444	0.60
Cement	....	....	....	....	135.00	....	135.00
Handling and hauling	....	....	465.00	....	587.00	....	1,168.00
Track and roads	....	....	100.00	....	106.00	....	635.00
Tools and plant	....	....	555.00	....	964.00	....	2,669.00
Incidentals	....	....	144.00	....	497.00	....	145.00
Engineering and supt.........	....	....	477.00	....	1,082.00	....	1,278.00
Total	....	....	$10,879	....	$10,902	....	$16,337

Note.—Dam No. 1 is 10 ft. high. 21 ft. wide at base, and 339 ft. long; No. 2 is 13 ft. high, 24 ft. wide at base, and 410 ft. long; No. 3 is 15 ft. high, 26 ft. wide at base and 650 ft. long.

hoists, unloading material at the wall and converting them into masonry. The itemized cost of the mason work was:

Foreman, 1 mo.	$ 90.00
Masons, 202 days of 8 hrs., at $2.80	565.60
Laborers, 35⅛ days of 8 hrs., at $1.20	42.15
Laborers, 270½ days of 8 hrs., at $1.00	270.50
Laborers, 369⅝ days of 8 hrs., at $0.80	295.70
Laborers, 146¾ days of 8 hrs., at $0.60	88.05
Boys, 83¼ days of 8 hrs., at $0.40	33.30
Wages paid in board	42.00
Fuel for hoists	18.49
Total, at 92½ cts. per cu. yd.	$1,445.79

It will be noted that the wages of laborers were very low. Doubtless the men were negroes.

On the south wall of Lock No. 2, Black Warrior River, during August, 1892, two gangs of masons, three masons to the gang, with helpers, laid and pointed 2,370 cu. yds., about 40% of which was dry rubble wall, the rest being first-class masonry in Portland cement mortar. This is 16 cu. yds. per mason per 8-hr. day. The following includes the cost of screening sand, mixing mortar, unloading materials at the wall, operating steam hoists, fuel for same, laying and pointing the masonry:

Foreman, 1 mo.	$ 100.00
Masons, 147½ days, at $3.50	516.25
Laborers, 27½ days, at $1.50	41.25
Laborers, 108 days, at $1.25	135.00
Laborers, 510½ days, at $1.00	510.50
Laborers, 216 days, at $0.80	172.80
Laborers, 186½ days, at $0.75	139.88
Laborers, 103 days, at $0.55	56.65
Boys, 87¾ days, at $0.50	43.88
Wages paid in board	100.00
Fuel	22.75
Total, at 77.6 cts. per cu. yd.	$1,838.96

Cost of Rock-fill Dams.—The three dams on the Black Warrior River, built by hired labor, were of the rock-fill type without mortar or core-walls. The down stream face is composed of large roughly dressed stones, laid in steps and doweled together. A timber crib is built into the upper face of the dam and sheathed with 6 x 12-in. plank. The dams were built during low water, without cofferdamming. Floating and stationary derricks were used. Sandstone for dams Nos. 1 and 2 was delivered by barge, and for No. 3 by rail, a track being laid on stone-filled cribs along the toe of the dam. The cost of this work is given in Table V.

		Crib No. 1.		Crib No. 2.		Crib No. 3.	
Lumber and iron	Ft.B.M.	34,453	$13.65	33,109	$12.68	33,109	$14.16
Carpenter work	Ft.B.M.	34,453	6.94	33,109	6.83	33,109	12.62
Filling rock	Cu. yds.	1,640	0.35	1,105	0.24	1,090	0.46
Total		......	$1,277	......	$909	......	$1,390

Note.—Crib No. 1 is 29 ft. 10 ins. high, 11 ft. 8 ins. wide, and 90 ft. long; Cribs Nos. 2 and 3 are 28 ft. 8 ins. high, 11 ft. 6 ins. wide, and 90 ft. long. The cribs are of 6 x 8-in. yellow pine with cross-pieces at intervals of 5 ft., drift-bolted together, and filled with one-man stone.

Cost of Cyclopean Masonry, Reference.—See the section on Concrete under Rubble Concrete.

Cost of Limestone and Sandstone Slope-Walls.—A slope-wall is practically a stone block pavement laid upon a sloping face of earth to protect it from erosion. The "wash" of passing boats in canals makes necessary some such protection of the earth in certain places. The beating of waves upon the sides of a reservoir or small lake acts in a similar manner, and a slope-wall is usually provided to resist the erosion. The concave side of a river bank is occasionally protected by slop-walling, with perhaps a line of piling at the toe of the wall.

A dry slope-wall, it will be seen, is an engineering structure often used, although very little exists in print as to its design or cost. Since the forces acting upon a slope-wall are not readily measurable, the design is an art, and not a science. Recorded ex-

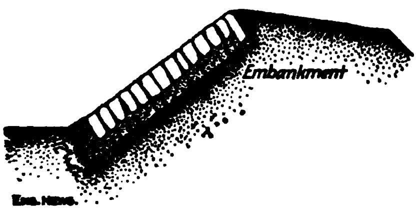


Fig. 2. Slope Wall.

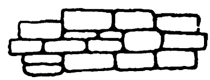


Fig. 3.

perience of others, personal experience of the designer and common sense should govern the design.

The oldest slope-walls on the Erie Canal were made of cobblestones rammed solidly into the bank, and placed so that the stones touched one another Cobbles for this purpose were gathered from fields or creek beds, and ranged in diameter from 4 ins. to 12 ins., the average being about 6 or 8 ins. These cobble slope-walls, while not as handsome as those made of dressed quarry stone, were in fact more durable, for the shales and limestone ledges along the route of the Erie Canal furnish stone more or less subject to weathering. Cobbles, or "hardheads," on the contrary, are often granitic and always tough.

Slope-walls made of quarry stone are built as shown in Figs. 2 and 3. The stones are split with wedges or plug and feathered, then roughly dressed with a hammer, and placed in the wall on edge, just as brick or stone block are placed in a street pavement. The longest dimension of the stone is laid parallel with the axis of the canal or river. In some of the earlier walls, huge slabs of stone were laid flatwise just as sidewalk flagging is laid, but such stones are apt to settle unevenly and tilt up so that a passing boat or moving ice will displace them entirely. Moreover it is practically impossible to bed very large stone properly, since ramming has no

effect. Experience, therefore, has shown the necessity of splitting up slabs into blocks readily laid and bedded by hand; and it costs no more in the end to build walls in this way, for the cost of handling with a derrick and cost of frequent moving of derrick more than offset the cost of splitting the stone. It is customary on the Erie Canal always to provide a lining of gravel (Fig. 1) back of the wall. This lining serves a twofold purpose: It makes it easy for the workman to bed jagged stone properly, and it further adds to the protection of the subsoil from wash. Waves beating through the joints in the slope-wall strike this gravel which is not easily displaced, and do not reach the subsoil with sufficient force to displace it. It is my opinion that this gravel lining is one of the most important and necessary features of a well-made slope-wall. Crushed stone, of course, would serve equally well or better, but usually the cost is more than for gravel. There are places where broken stone costs less than gravel and in such places it should be used.

On rivers or reservoirs, subject to wide fluctuation in water level, the gravel or stone lining for the paving is even more necessary; for there the surface rain water, flowing down over the face of the slope-wall, will cut rivulets beneath it unless proper lining is provided. Embankments are usually so designed as to prevent much rain water from flowing over the slope-wall face, as shown in Fig. 1, where the towpath is seen to have a slope away from the canal. In diking a river the same form of top slope is usually provided where a slope-wall is to be laid; but in protecting a natural river bank it is often impossible entirely to prevent rain water from flowing over the face of the slope-wall. Ditches should be dug to divert the rain water, which is then carried in a pipe culvert through to the river. Ditches, however, are apt to fill up with washed-in earth, so that in any event a substantial lining of gravel should be placed back of the slope-wall, in order to guard against erosion by rain water. A thickness of gravel lining of from 4 to 8 ins. will suffice, 4 ins. ordinarily being enough.

Passing to the thickness of the stone slope-wall itself, we find a range of from 6 ins. to 24 ins. with 12 to 16 ins. most commonly used. The Chemung River, near Elmira, N. Y., is a stream about 600 ft. wide and 20 ft. deep in times of high water. At one place on this river a slope-wall 24 ins. thick was built by the State, and a few miles away another had been built 12 ins. thick, both of a shaley limestone. Both walls have served for years, except in places where the piling at the toe has been undermined. The 24-in. wall was evidently an extravagant design; and not justified by the conditions, particularly as the lighter wall had been in service some years before the construction of the 24-in. wall was begun. Because a river is occasionally a raging torrent it does not follow that the floating debris or ice will displace the small stones of a well-laid slope-wall. As a matter of fact, each stone is held by the weight of stones above, even when laid on a 1½ to 1 slope, and a stone is pried out of a slope-wall with great difficulty. I believe

that ordinary brick laid dry as a slope-wall pavement will protect a river embankment perfectly, provided the subsoil does not become undermined. In slope-wall masonry, on river embankments subject to blows of ice and logs, a thickness of 8 to 10 ins. seems an advisable minimum, for some erosion and settlement of the subsoil or lining must be provided for. On reservoirs or canals a less thickness may be used where blows from boats are not frequent But as above stated 12 ins. is very often specified, and as will be seen later, it is not an extravagant depth. Having fixed upon the depth of stone to be used in the wall, the thickness (or rise) and length remain to be determined. A minimum thickness of 4 ins. is usually specified. As a matter of fact, except for appearance sake, thickness is not an important factor. An engineer who is fond of seeing coursed masonry will often require that the slope-wall be laid in courses of a specified minimum and maximum thickness. It costs money to dress the stone to lay in such courses, but for appearance sake, near a highway, such expense may be justified. Ordinarily it is not justifiable. Slope-walls are built for protection, not for beauty.

If any definite minimum thickness of courses is specified, it should be governed by the stratified thickness of stone in the nearest quarry. If the quarry is thick-bedded limestone, then it is safe to omit any minimum thickness requirement; for to split into thin slabs with plug and feathers is expensive, and the contractor will surely not split the stone thinner than the maximum thickness specified. If the quarry stone is thin-bedded, as shaley limestone and some sandstones are, a minimum thickness of 3 or 4 ins. may be named. A maximum thickness of 10 or 12 ins. is a reasonable requirement. A minimum length of 12 ins. is often specified, and is not unreasonable, for slabs are readily broken with a hammer to almost any desired length. There is no objection to stones up to 24 ins. in length.

Slope-wall paving is "laid to break joint," as shown in Fig. 3, and it is well so to lay it, because if the toe is washed out, this breaking of joint enables the wall above to span the space, and so prevents rapid crumbling away of the wall. However, specifications are often drawn with absurd refinement as to this bonding; the least admissible number of inches of bond is named, and altogether the wall is treated as if it were to be a bridge pier, or arch, or other necessarily strong structure. To require that the stones shall be laid so as to break joint is a sufficient requirement for slope-wall work.

We come now to the feature of the specifications that makes a wall cost little or much—the allowable maximum width of bed and end joints. Specifications sometimes name ½-in. joints to the full depth of each stone. Such work, as we shall see, costs twice as much as under the more reasonable requirement of 1½-in. joints, carried back 4 ins. from the face beyond which the stone may fall away to a wedge shape. To call for joints of less than 1½ ins. is justifiable only where well coursed slope-walling is desired for

appearance sake. Wall with 1½-in. maximum joints serves the purpose of protection from erosion, and any expense incurred in better dressing is merely "for looks."

In laying a slope-wall, "frames" or "profiles" should be set about 20 or 25 ft. apart, as shown in Fig. 4. Stakes are driven as shown, and a 1 x 4-in. profile-stick of timber is nailed to the stake at the proper grade, as determined by the Y-level. The workmen then stretch a string from the bottom of one frame to the bottom of the next one, and thus have a line to which they can accurately lay the face of the slope-wall. Never allow a workman to attempt to lay slope-wall without such frames and a cord to guide him; for without such guides he will surely lay a wall with humps and hollows. Another point in practical laying is always to incline each stone lightly uphill. Do not try to set it exactly at right angles to the surface of the ground, for an endeavor to do this results in a wall like that in Fig. 5, where the stone are in steps.

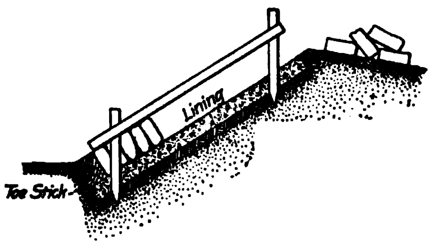


Fig. 4. Profiles.

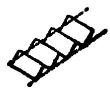


Fig. 5.

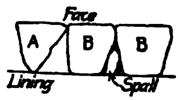


Fig. 6.

It is an excellent plan to set the profile strips exactly 13½ ft. apart, for reasons given later on.

The stone are split with plug and feathers and hammers in the quarry, hauled by wagons and dumped at the top of the embankment as in Fig. 4. Laborers then throw the stones down to the slope-wall masons, who roughly scabble and lay them, filling in the chinks back of the face with spalls and gravel lining. An intelligent laborer can soon learn to lay common slope-wall, but skilled slope-wall masons, if available, usually lay a better-appearing wall at less cost. Sharp-pointed stones like *A*, Fig. 6, should ordinarily not be allowed; but stones like *B*, that are roughly dressed, 3 to 4 ins. back of the face, and then fall away so as to leave a wide end joint as shown, are not objectionable, provided these joints are filled with spalls and gravel.

Before passing to a consideration of costs, a word should be given as to protecting the toe or foot of the wall. In canal work it is customary to lay a 12 x 12-in. toe-timber or stick, as shown in Fig. 4. Since timber continually submerged does not rot, and

since frozen timber in the winter when canals are closed does not rot either, this design is not objectionable for canals. However, I question the necessity of using a toe stick at all under ordinary conditions in canal work. In river work, a toe stick resting against piles driven 5 ft. c. to c., is often used. In some cases the toe stick is done away with entirely and a line of close-driven piles substituted, which is a very expensive solution of the problem and not altogether satisfactory. Piling on the concave bank of a river seems to hasten rather than retard undermining. A brush mattress is a better toe protection under such conditions, and heavy rip-rap is still better where the brush is alternately wet and dry.

The following are actual costs of work that I have done. The quarry required very little stripping, and was located on a side hill, 2½ miles from the work. The stone was a thin bedded limestone, rather shaley, and was barred and wedged out with the use of little or no powder. There was very little plug and feathering as the stone split readily under the hammer. Common labor was employed, the only skilled man being the foreman, who worked with the men.

One hundred and forty wagon loads of stone, each load measuring 2 cu. yds. corded upon the wagon, and 1.55 cu. yds. laid in the slope-wall, making a total of 220 cu. yds. in the wall, were quarried and loaded by five men (including the foreman) in 20 working days of 10 hrs. each, or at the rate of 2.2 cu. yds. of slope-wall quarried per man per day. Laborers received $1.50 a day and foreman $2.50, so the wages averaged $1.70, which, divided by 2.2, makes the cost nearly 80 cts. per cu. yd. for quarrying and loading the stone. Each driver helped load and unload his wagon, and hauled 4 to 5 loads a day. A team and driver received 70 cts. a load for hauling (5 miles round trip) over a good hard gravel road with no upgrades; so the cost of hauling was about 45 cts. per cu. yd. of slope-wall, making a total of $1.25 for the stone delivered at the work. A quarry rental of 10 cts. per cu. yd. was paid for the stone. To estimate the cost of loading and hauling for other distances the following observations were made: Two laborers working quite deliberately handed up the stone to the driver, who stacked them on his "stone rack" (3 x 11 ft.), or wagon box without sides other than a strip of 4 x 4-in. timber. It required 15 mins. to load a wagon with 2 cu. yds. measured on the wagon, or 1.55 cu. yds. in the slope-wall. The driver alone would unload his wagon at the dump in 7 mins., by simply rolling the stone off.

The team traveled at a speed of 2½ miles an hour, or 220 ft. a minute, at a walk, and generally trotted part of the way back to make up for lost time at both ends. With a short haul, or over soft roads trotting would have been out of the question; and over very soft earth roads with occasional steep pulls a load half as great as the above is the maximum.

On another similar contract 750 cu. yds. of slope-wall were quarried at a cost of $1.10 per cu. yd., the stone being a "grit" or shaley limestone, quarried by laborers at $1.50 per day of 10 hrs.

The haul was 1¾ miles from quarry to wall and 6 trips a day were made by each team, hauling 1¾ cu. yds. each trip as measured in the wall, at a cost of 35 cts. per cu. yd. for hauling. This stone, therefore, cost $1.45 per cu. yd. delivered.

In laying 750 cu. yds. of "second-class" slope-wall, 12 ins. thick, joints 1½ ins. as a maximum, stone allowed to fall away 4 ins. back of face, not laid in courses, but an excellent wall in appearance and in reality, the cost was as follows: The first few days, using new hands, intelligent laborers, each man laid 2½ cu. yds. at a cost of 60 cts. a cu. yd., wages being $1.50 per 10-hr. day. Later these men readily averaged 3 cu. yds. per day. Some skilled slope-wall layers were imported and received $2.50 per 10-hr. day. These men readily laid 5 cu. yds. each day, one laborer to every four slope-wall layers acting as a helper to deliver stone. Thus 600 cu. yds. of slope-wall were laid in 130 layer-days and 35 helper-days, half of the layers being skilled men, and half common laborers. There was no foreman in constant attendance, as each man's work between the frames was easily measured up, and his daily progress thus known. A portion of the work was sublet at 50 cts. per cu yd. to two of the skilled slope-wall masons who had each been averaging 5 cu. yds. a day. From that time on each averaged 7½ cu. yds. of wall daily. Skilled men like these under subcontract will lay 10 or even 12 cu. yds. of a somewhat rougher slope-wall in 10 hrs. On another contract where the wall was 16 ins. thick, 4 masons at $2.50 and 4 laborers at $1.50 averaged 60 cu. yds. of fair slope-wall per 10-hr. day. Work was scarce, and one of the masons was the subcontractor himself, and received 30 cts. per cu. yd. Assuming 50 cts. per cu. yd. as a fair average cost for laying good "second-class" slope-wall and $1.25 to $1.50 for cost of stone delivered, we have a total cost of $1.75 to $2.00 per cu. yd. in place.

The average contract price for slope-wall on the Erie Canal deepening in 1896-7 was $2.50 per cu. yd., wages being as above given. Slope-wall laid in courses, with close joints the full depth of the wall, no course less than 6 ins. thick—a sand-papered job—was let for $4.50 per cu. yd. under conditions where $2.50 was a fair price for good ordinary slope-wall. The actual cost was not far below the contract price for stone plug and feathered to size cost delivered $2.50 per cu. yd., and laying cost $1.25 per cu. yd. Gravel lining in both cases was paid for separately, the contract price along the Erie Canal averaging 90 cts. per cu. yd. of lining in place. The actual cost of this lining is of course figured as for any earthwork, an allowance being made for spreading it on the face of the embankment after dumping it. To spread it most expeditiously it will pay to make a wooden chute into which the gravel is shoveled from the wagons, a shoveler helping the driver to unload. Two men will unload 1 cu. yd. in this way in 10 minutes, if they work as they should. The driver then has a rest on his return trip, at the end of which it is well to provide an extra wagon, which has been loaded during his absence. It takes only

1½ mins. to change the team from the empty to the loaded wagon. Since 1 to 1¼ cu. yds. of gravel constitute a load, since teams travel 220 ft. per min., and since a laborer can load 18 cu. yds. of gravel in 10 hrs., we have all the factors necessary to compute the cost of hauling and unloading. There is very little work in spreading the gravel where a chute is used, 2 to 5 cts. per cu. yd. covering this item.

If good thin-bedded sandstone or limestone is not available, it may be necessary to plug and feather the stone to sizes specified, and this cost may be estimated by data on page 492.

In order to secure the most economic results, slope-wall masons should be paid on the bonus system. To do this, the profile strips are set 13½ ft. apart, so that every lineal foot on the strip means ½ cu. yd. of slope-wall, if the wall is 1 ft. thick. Each mason is assigned to one lot, between two profile strips, and the lots are numbered consecutively with red chalk marks on the posts. The profile strips are of 2 x 4 dressed pine, painted with foot marks, so that a timekeeper can see at a glance the height to which the wall in any given lot has reached at the end of the day. There is no measuring to be done after the strips are nailed in place, yet the timekeeper and the masons themselves can keep a perfect record of daily progress. After the work has been under way a short time, it will be evident that a laborer to every two masons, say, will be necessary to deliver stone down the slope. At first the average output is but little better than before, but certain of the masons will do much better than the average. Their wages are then increased and perhaps two or more of the slower masons are discharged. Immediately, if there are no unions to interfere, the output of the men increases. At the end of a week I have had the average yardage increase 50%, and individual yardage increase much more, the quality of the workmanship remaining as before. The men receive higher wages and the contractor increases his profits, both by virtue of the greater output and by reducing the cost of supervision. I have been away from such work, after organizing it, for two weeks at a time, without a foreman in direct charge, yet the output has not fallen off. A more effective plan than merely to increase the daily wage is to pay a bonus per cubic yard for every yard in excess of, say, 3 cu. yds. laid per day.

Cost of Granite Slope-Wall.—The cost of a granite slope-wall greatly exceeds the cost of slope-walls of stratified rock such as are described in the preceding paragraphs, if any attempt is made to square the granite slope-wall stones, for rubble granite stones must be plug and feathered on all faces to square them up. Even where the specifications are lenient, if an attempt is made to secure a granite slope-wall with a smooth face, but without close joints, the cost of plugging off the faces of stone before laying, and the cost of reducing them to a size not greater than the thickness of the wall (12 to 18 ins.) is not a small item. If granite boulders, or granite rubble stones from a quarry, are to be used, first estimate

roughly the average size of each stone, then estimate the number of plug-holes necessary to split it into slope-wall stones. Use the data on page 492 for estimating the cost of this plug and feather work.

On one job of granite slope-wall work, 3 masons splitting field boulders with plugs, and 10 laborers laying a wall 18 ins. thick, averaged 14 cu. yds. per day of 10 hrs. for $24, or $1.70 per cu. yd. for splitting and laying the stones. No attempt was made to secure close joints or to lay the stone in courses. Stones were frequently laid flatwise and bedded in spawls; and spawls were used liberally between joints. The masons were rapid workers, but the laborers were a slow lot of men.

Cost of Laying a Limestone Slope-Wall.—Mr. W. B. Fuller says. "The paving of the upper sides of the sedimentation basin (Albany, N. Y.) is of blue limestone blocks, 10 to 15 ins. deep, 8 to 20 ins. wide, and 15 to 36 ins. long. Two masons and one helper together would lay about 16 sq. yds. per day, and the labor cost of laying the stone and gravel, including the teaming of the material about 800 ft., was 72 cts. per sq. yd."

The specifications called for a slope-wall 10 ins. thick laid on a gravel lining 24 ins. thick.

Cost of Slope Wall Paving.*—Maj. Graham D. Fitch gives the following:

In paving the bank of the Upper White River, selected sandstone (bluestone) was used, the pieces being set on edge and rammed. A coat of gravel was then swept over the paving. The work was done by Government forces; common laborers receiving $1.50 for 8 hrs.

The cost of grading and paving behind the land wall was as follows:

Material.	Unit cost.	Total.	Per sq. yd. Paving.
Riprap stone, 798 cu. yds.......	$0.74	$590	$0.307
Cement, 5 bbls.	1.97	10	.006
Total materials		$600	$0.313
Labor:			
Insp. of riprap stone, 798 cu. yds.	$0.008	$6	$0.003
Insp. of cement, 5 bbls.........	.022	....	....
Grading and paving 1,916 sq. yds.	.495	947	.493
Total labor		$953	$0.496
Grand total, 1,916 sq. yds.........		$1,553	$0.810

The total labor time for the 1,916 sq. yds. of grading and paving was 550⅛ days, the work done per man per day being 3.49 sq. yds., or 1.45 sq. yds.

It will be noted that 1 cu. yd. of stone made 2.4 sq. yds. of

*Engineering-Contracting, May 6, 1908, p. 283.

pavement, showing that the thickness was 15 ins. The labor of grading and paving was $1.18 per cu. yd.

At another place the cost of slope-wall pavement was as follows:

Material:	Unit cost.	Total.	Per cu. yd.
Riprap, 693 cu. yds.	.74	$513	$0.74
Labor:			
Paving, 425 days	...	$835	$1.20
Inspection of riprap, 8 days	...	15	.02
Total		$850	$1.96
Grand total, 693 cu. yds. placed		$1,363	$1.96

The amount of paving done per man per day was 1.16 cu. yds.

At another place the cost was:

	Unit cost.	Total.	Per cu. yd.
Riprap, 438 cu. yds.	$.74	$324	$ .74
Labor, 202⅞ days	....	374	.85
Grand total, 438 cu. yds.		$698	$1.59

The average work done per man per day was 2.1 cu. yds. of riprap placed.

Cost of Riprap on a River Bank.*—Maj. Graham D. Fitch gives the following:

The work was done on the Upper White River, by Government forces, common laborers receiving $1.50 per 8-hr. day. Sandstone was used.

The following was a piece of bank revetment, the riprap being laid roughly by hand to a depth of nearly 12 ins. There were 3,588 sq. yds.:

	Unit cost.	Total.	Per sq. yd.
Riprap, 1,235 cu. yds.	$0.74	$914	$0.254
Inspection of riprap, 1,235 cu. yds.	.008	10	.002
Placing riprap, 1,235 cu. yds.	.245	302	.084
Total		$1,226	$0.340

The labor time for placing the 1,235 cu. yds. of riprap was 156 days, and each man placed an average of 7.92 cu. yds. of riprap per day. On the basis of 3,588 sq. yds. of revetment each man placed an average of 2.3 sq. yds. per day.

At another place riprap was placed on a brush mattress for bank revetment. The bank thus protected was 450 ft. long by 44 ft. wide (measured along the slope). The bank was graded by 124 man-days, at a cost of $229, or 18 sq. yds. per man-day.

The cost of riprapping the bank was as follows.

	Unit cost.	Total.	Per cu. yd.
Riprap, 1,044 cu. yds.	$0.74	$768	$0.74
Paving, 109⅞ days	....	206	.197
Inspection of riprap, 14 days	....	26	.024
Grand total, 1,044 cu. yds.		$1,000	$0.96

The work done per man per day was 8.42 cu. yds. of riprap placed.

**Engineering-Contracting,* May 6, 1908, p. 288.

There were 2,200 sq. yds., hence the cost per sq. yd. was 9.4 cts. for labor, and 35 cts. for stone.

Cost of Riprap and Brush Mattress, Cross-Reference.—Data on this will be found in the section on Timberwork. Consult the index under "Brush Mattress."

Cost of Riprap in a Crib Dam.*—Maj. Graham D. Fitch gives the following:

The work was done on the Upper White River, by Government forces, common laborers receiving $1.50 for 8 hrs. The stone was sandstone.

In filling the pockets of a crib dam 324 ft. long, 8,000 cu. yds. of riprap were used, at the following cost:

	Per cu. yd.
Riprap stone	$0.74
Labor filling crib	0.43
Total	$1.17

Each laborer averaged 4 cu. yds. filled per day.

On a small crib near one abutment of the dam, 527 cu. yds. of riprap were put in at the rate of 4.45 cu. yds. per man-day.

On a foundation crib for the abutment of the dam, 876 cu. yds. of riprap were put in at the rate of 6.84 cu. yds. per man-day.

Cost of Riprapping Cribs.†—The following data relate to the cost of riprapping cribs with breakwater stone at Ashtabula Harbor. Ohio. The stone was loaded from the dock into a derrick scow by the derrick, the scow was then towed an average of one-fourth mile and the stone placed, as riprap, behind new crib docks which had just been completed. The object of this crib backing was to protect the cribs from storms and also to relieve them of any lateral thrust which might cause them to move. The derrick scow used in handling the stone holds a maximum deck load of about 125 tons. The derrick boom is about 50 ft. long and all movements of the derrick are operated by steam.

The stone was placed in a mound of a triangular cross-section against the cribs, the apex of this right-angle triangle being at the water surface. The depth of water at the site of work averaged about 15 ft.

The stones used were irregular in shape, weighing 160 lbs. per cu. ft., the total average weight of each stone being about one ton.

The cost records below are for the months of May and June, 1907, and embraces the entire operation of riprapping the cribs, the work including: Loading the stone from the dock onto the deck of the scow; towing the scow from the dock to the site of the new cribs, an average distance of about one-fourth mile; unloading the stone behind the cribs as riprap; towing the scow from the

*_Engineering-Contracting_, May 6, 1908, p. 285.
†_Engineering-Contracting_, July 31, 1907.

cribs back to the dock to be loaded again; time due to bad weather and breakdowns, interest and depreciation on value of plant and miscellaneous expense.

The scale of wages per 10-hr. day was as follows:

Foreman (who was also steam engineer)......	$3.00
Deck hands	2.00
Watchman	1.75

The cost of backing the cribs with breakwater stone for month of May, during which time 661 tons of stone were placed, was as follows:

	Total.	Per ton.
10 transfers by tugs, at $5..........................	$ 50.00	$0.075
6 tons coal, at $2.70..........................	16.20	.024
Labor, placing stone..........................	47.15	.071
Lost time due to bad weather and breakdowns..	31.60	.048
Interest and depreciation on value of plant......	90.00	.136
Miscellaneous	10.00	.015
Total	$244.95	$0.369

The cost of backing the cribs for the month of June, during which time 1,380 tons of stone were placed, was as follows:

	Total.	Per ton.
24 transfers by tugs, at $5..........................	$120.00	$0.087
17 tons coal, at $2.70..........................	45.00	.032
Labor, placing stone..........................	189.15	.140
Lost time, due to bad weather and breakdowns..	42.50	.030
Repairs and miscellaneous..........................	38.55	.043
Interest and depreciation on value of plant......	90.00	.065
Total	$545.20	$0.397

In the above tables the item "placing stone" includes the loading of stone on the scow from the dock and placing it behind the cribs. The labor cost of these two portions of the work were about equal. Interest and depreciation on plant was taken as 15% per annum and was distributed over five months. The item "miscellaneous" includes wages of watchman on Sundays, and a few supplies, such as engine-oil, waste, manila lines, etc. The repairs shown in the record for June consisted of repairing the damage due to a boom being dropped by accident and breaking in two.

On the basis that the weight of the stone was 160 lbs. per cu. ft., the cost per cubic yard for riprapping the cribs was as follows: Month of May, 80 cts.; month of June, 85 cts.

For the above information we are indebted to Mr. E. C. Bowen, Jr., Assistant Engineer, Lake Shore & Michigan Southern Ry.

[For further data on riprap, see the index under "Riprap."]

Cost of Riprap Stone, References.—For the cost of quarrying and handling stone see the sections on Rock Excavation and on Stone Masonry. Also consult the index under "Riprap," for contract prices of riprap are given in the section on Railways and elsewhere.

Cost of Cleaning Masonry With Acid.—Mr. C. M. Saville gives the following relative to the cost of cleaning masonry with acid.

The granite ashlar masonry of a reservoir gate chamber had been pointed with 1:1 Portland cement mortar late in the fall, during very cold weather. In order to work quickly the pointing mortar was mixed very wet, and consequently dripped over the ashlar, giving an unsightly appearance. In the spring, the pointing was removed, the stone washed with acid, and then repointed. About 560 sq. yds. of stone facing were thus gone over in 9 days by 2 men at a total cost of $50, or 9 cts. per sq. yd. for labor. Dilute muriatic acid was used, 1 part acid to 2 parts water, applied with old paint brushes; 4 gals. of acid were required, or 1 gal. for 140 sq. yds. The two men were engaged 5 days removing pointing, 2 days cleaning stone, and 2 days repointing.

For other data, see the index under "Masonry, Cleaning."

Cost of Excavating Masonry.—The masonry abutments of an old bridge were removed to make way for a new arch bridge. A hand-power derrick was used, and the material was piled near the derrick. The cost of excavating this masonry was 50 cts. per cu. yd., wages being 15 cts. per hr. In another similar case the cost was 75 cts. per cu. yd. The average contract price for such work on the Erie Canal, in 1896, was 80 cts. per cu. yd., wages being 12½ cts. per hr.

Mr. C. R. Neher informs me that the cost of excavating 3,140 cu. yds. of old railway bridge piers, and depositing the material in the river bed, was 38 cts. per cu. yd., not including the cost of scaffolding.

For other data on masonry excavation, see the index under "Masonry, Excavation."

Cost of Pointing Old Bridge Masonry.—Cleaning and pointing old masonry, using Alpha cement at $2.40 per bbl., masons' wages being $2 and helpers $1.60 per day, cost as follows:

Small jobs; no staging:	Cts. per sq. ft.
Cement	0.26
Labor	0.74
Total per sq. ft.	1.00

This is equivalent to 9 cts. per sq. yd.

Large jobs; staging used:	Cts. per sq. ft.
Cement	0.27
Labor	1.87
Total per sq. ft.	2.14

This is equivalent to 19 cts. per sq. yd.

For other similar data, see the index under "Masonry, Pointing."

Cost of Lining Tunnel With Masonry.—Drinker gives the following data on the lining of Carr's Tunnel (826 ft.) on the Pennsylvania R. R. in 1868-1869:

Brickwork.— Six hundred and nine thousand brick in the arch (5% broken and lost); 10.44 bushels of neat cement (no sand used in the mortar) laid 1,000 bricks, the mortar forming 30% of the

brick masonry; the arch was 25 ins. thick, 24½-ft. span and 9-ft. rise:

	Cost per M.
Bricks, f. o. b.	$ 8.80
Loss in handling	0.51
Unloading and delivering	1.92
Laying	5.84
Cement	5.10
Total	$22.17

Bricklayers received 40 cts. per hr.; helpers, 17½ cts. per hr.; carpenters, 27½ cts. per hr.; laborers, 17 cts. per hr.

Stonework.—One thousand seven hundred and thirty perches (25 cu. ft.) of rough masonry for side walls, presumably sandstone; 187 perches of ring stone; 25 perches wasted in dressing. The bench walls were 4 ft. wide at the bottom, 3 ft. at the top and 13 ft. high:

	Cost per perch.
Quarrying (1,730 perches)	$ 4.80
Cutting (1,730 perches)	4.36
Hauling (1,942 perches)	1.06
Handling and laying (1,917 perches)	2.80
Cement, 1.65 bu. per perch (8 1/6% of the masonry)	0.81
Total	$13.83

Stonecutters and masons received 35 cts. per hr.; quarrymen, 17½ cts. per hr.; laborers, 17 cts. The stone side walls were laid in 8 courses averaging 2 ft. thick each; hence there were 52,800 sq. ft. of beds cut; and estimating each stone 3 ft. long and dressed for 1½ ft. back of the face on joints, there were 14,300 sq. ft. of joints; making a total of 67,100 sq. ft. of cutting which cost 11.2 cts. per sq. ft. This is said to have been too high a unit cost, and the accuracy of the measurements is questioned.

Arch centering cost $1,400, to which was added $600 for moving the centering forward from time to time; making $2.40 per lin. ft. of tunnel, to which must be added $0.70 per lin. ft. for scaffolding.

For further data on tunnel lining, see the index under "Tunnel, Lining."

Cross-References.—Other data on stone masonry will be found in various parts of this book, for which see the index under Masonry.

SECTION VI.

CONCRETE AND REINFORCED CONCRETE CONSTRUCTION.

Definitions.—See also the definitions in Section V on Stone Masonry.

Aggregate.—The broken stone or gravel used in concrete. The word *ballast* is also used in this sense.

Batch.—The amount of concrete mixed at one time either by a gang of men or by a machine mixer. In hand mixing, ordinarily one barrel of cement and the proper proportions of sand and stone make a batch.

Cement.—A preparation of calcined clay and limestone, or their equivalents, possessing the property of hardening into a solid mass when moistened with water. This property is exercised under water, as well as in open air. Cements are divided into four classes: Portland, Natural, Puzzolan and Silica cement.

Portland cement is the finely pulverized product resulting from the calcination to incipient fusion of an intimate mixture of properly proportioned argillaceous and calcareous materials, and to which no addition greater than 3% has been made subsequent to calcination.

Natural cement is the finely pulverized product resulting from the calcination of an argillaceous limestone at a temperature only sufficient to drive off the carbonic acid gas. A few years ago it was common practice to give to all natural cements the name Rosendale cement, for it was at Rosendale, N. Y., that the first natural cement was made in this country.

Pozzolan is an intimate mixture of pulverized granulated furnace slag and slaked lime without further calcination which possesses the hydraulic qualities of cement.

Silica cement (or sand cement) is a mixture of clean sand and Portland cement ground together.

Concrete.—An artificial stone made by mixing cement mortar with gravel or broken stone. The proportions of cement, sand and stone are generally expressed in parts by measure (occasionally by weight). A 1:2:5 (one, two, five) concrete means 1 part cement to 2 parts sand to 5 parts stone. A 1:3:6 concrete is made of 1 part cement, 3 parts sand and 6 parts stone (or gravel). When both stone and gravel are used, the concrete may be desig-

nated thus, 1:3:2:4, which means 1 part cement, 3 parts sand, 2 parts gravel and 4 parts stone.

Dry concrete is a term used to designate a mixture containing so small a percentage of water that very hard ramming is required to flush the water to the surface.

Wet concrete contains so much water as to require little or no ramming. "Sloppy concrete" is concrete so wet that it will run down a slightly inclined trough.

Concrete that is mixed *dry* is spread in layers 6 or 8 ins. thick and *rammed* or *tamped* until the water flushes to the surface. Concrete that is mixed *wet* is *spaded* with a spade-like tool that is worked up and down in the concrete to remove all air bubbles particularly near the forms or near any steel used to *reinforce* the concrete.

The terms *crushed stone* and *broken stone* are used indiscriminately to designate stone that has been broken by a rock crusher.

Crusher run means all the crushed stone just as it comes from the crusher, without separation into sizes, and generally it includes the product that would be termed screenings if it were screened out.

Facing.—(1) A rich mortar placed on the exposed surfaces to make a smooth finish. (2) Shovel facing by working the mortar of concrete to the face.

Forms are the *molds* (usually of lumber) that hold the concrete in shape until it has *set* or hardened.

Matrix is a term sometimes used instead of mortar, but there is no good reason for using the term at all.

Molds.—See Forms.

Reinforced concrete is concrete in which are embedded bars or wires of steel or iron. It is often called *concrete-steel.*

Rubble concrete is a term applied to concrete in which large rubble stones, or *plums,* are embedded. Stones from the size of a man's head to the size of a barrel are thus used. When larger stones are used, and the concrete becomes simply a coarse grained mortar between them, probably the term *cyclopean masonry* is more correct than *rubble concrete;* still there is no distinct dividing line.

Screenings applies to the product of the crusher that passes through the smallest screen used. The size of the smallest hole in the screen varies from ⅛-in. to ¾-in., so the word screenings has no definite meaning, although it can usually be taken to apply to all stone under ½-in. in diameter.

Sylvester wash.—A waterproofing wash consisting of alum and soft soap applied alternately to the surface of concrete.

Voids is a term applied to the spaces between the grains of sand, or to the spaces between the fragments of broken stone. The voids are expressed in a percentage of the total volume of the loose material.

Magnitude of the Subject and General Discussion.—I have spoken of earth excavation as being a subject of great magnitude. But

the subject of concrete is even greater. This is well indicated in the citation even of a few of the important books on concrete which will be found at the end of this section.

Mr. Charles S. Hill, of the editorial staff of *Engineering-Contracting*, and I have collaborated in writing a 700-page book* devoted solely to the methods and cost of concrete and reinforced concrete construction. Yet there is practically no duplication in our book of the matter in Reid's great treatise, "Concrete and Reinforced Concrete Construction," in whose 900 pages the subject of the design of concrete construction is elaborated.

It will be evident, therefore, that in the space devoted to concrete in this handbook, only the principles of the methods and cost of construction can be given, supplemented by a few illustrative examples. However, the reader will find a good many more examples in other sections of the book, notably the sections on Bridges, Sewers, Waterworks, Pavements, and Buildings, for which consult the index under "Concrete."

While, at first glance, estimating the cost of concrete may seem difficult, it is in reality a comparatively simple task when the cost is divided into separate items and sub-items. Then the reason why the concrete base of a pavement costs say, $3.50 per cu. yd., while the cost of a reinforced concrete building is, say, $15 per cu. yd., is made very clear.

In considering variations in published cost data one should always bear in mind that there are not only many different ways of doing the same thing, but that workmen vary greatly in efficiency. The latter element depends mainly on the management, and it is a particularly important factor in this comparatively new branch of engineering work—concrete construction. I have received several letters from experienced concrete contractors questioning the accuracy of certain costs of concrete work that I had published, because, it was said, no such low costs had ever come under their observation. This was doubtless true and it was for just that reason that I had published those low costs; for, accompanied by the methods of doing the work, those records showed what thoroughly efficient workmen under good management could accomplish. I go so far as to say that unit costs of concrete work that are now regarded as being very low will, before long, seem exceedingly high—unless it should happen that rates of wages and prices of materials rise sufficiently to offset entirely all improvements in machines, methods, and management.

There is not the slightest doubt, for one thing, that we are using too much cement in most of our concrete. Rarely do we see American specifications requiring less than 0.9 bbl. of cement per cu. yd., although there are many classes of heavy concrete work for which 0.5 to 0.6 bbl. of cement per cu. yd. would suffice.

We have excellent machines for mixing concrete, but compara-

*"Concrete Construction—Methods and Cost," by Gillette and Hill.

tively few contractors know how to transport the materials to and from the mixers with any great degree of economy.

Not only do poor designs of forms, but inefficient workmanship in framing, erecting and shifting them, usually run up the cost of formwork far above what it should be. Incidentally I may say that it is my opinion that the oft-berated method of intrusting both the design and erection of concrete buildings to firms of constructing engineers is a method that is likely to grow more popular. In spite of the objection that the designer should not be also the contractor for the structure, there is one very important element to consider, and one that seems to me to offset entirely any objection. *The concrete contractor who is also a designer will so design as to be able to use his forms again and again on many different buildings of the same character.* Eventually this will lead to the wide use of steel forms for certain classes of work, and thus reduce the item of form cost still more.

The manufacture of concrete in slabs, beams, boards, etc.—a sort of concrete lumber—is certain to become common, and will greatly reduce the cost of many classes of concrete work. Why, for example, should not rough retaining walls be built of concrete beams, or sticks, exactly as timber bulkheads are now made on railway work in timbered countries? By casting dovetailed shapes on the ends of the sticks, and corresponding recesses in other beams, it would be a simple matter to build such a concrete retaining wall of concrete, say 8 x 12 ins., in cross-section, with "anchors" of similar concrete sticks extending back into the earth filling that is placed back of the wall. In this manner a wall only 8 ins. thick, with each course anchored to the earth fill, could be built by unskilled laborers at a very low cost. The concrete sticks would be made in a yard, hauled to the site of the work, and erected with a light A derrick or moved on "dolleys" up an incline, just as heavy timbers are now handled.

In spite of the questionable success, thus far, of reinforced concrete cross-ties for railways, there is abundant reason to believe that such ties will eventually be perfected, thus leading to the making of concrete lumber in great quantities.

I am satisfied that thin concrete slabs, both in the form of concrete lumber and made in place by plastering mortar upon a reinforcing sheet or mesh, are destined to play a very important part in the construction field. Flues for carrying hot smelter gases have been made of expanded metal plastered on both sides with cement mortar. Why should not tall smokestacks be made in the same way? It might be necessary to give a large flare to the base. Eiffel Tower fashion, in order to secure stability when anchored to a concrete base. The great advantages of this method of plastering cement mortar upon a steel skeleton are two: (1) The ability to build concrete work without any forms at all; and (2) the ability to secure an exceedingly thin structure of great strength and durability.

With these and kindred possibilities of development of concrete

construction along lines of greater economy, it is not likely that the lowest construction costs given in this book will look very low to readers of its next edition.

Cost of Manufacturing Cement.—Boilleau & Lyon give the following cost of manufacturing slag cement:

"The following figures may be relied upon as absolutely accurate. They represent the writer's experience as treasurer and general manager of the Maryland Cement Co. of Baltimore."

Cost for an output of 5,000 bbls. per month:

	Per bbl.
Mill force, labor and supt.	$0.160
125 tons coal per mo., at $3.05	0.076
3,000 bu. lime per mo., at $0.16	0.100
900 tons slag per mo., at $0.50	0.090
Repairs, $100 per mo.	0.020
Oil and grease, $40 per mo.	0.007
Contingencies	0.011
Total	$0.464
Administration	0.121
Grand total	$0.585

The same authorities give the following estimate of cost of manufacturing Portland cement in Pennsylvania in 1904.

The figures are based on an output of 1,200 bbls. per day, using 60-ft. kilns, and are the results of actual experience in Pennsylvania.

	Per bbl.
Labor:	
Quarry	$0.050
Stone house (2 men each shift)	0.005
Mill building (6 men each shift)	0.015
Kiln room (4 men each shift)	0.015
Engine and boiler room (4 men each shift)	0.015
Fuel mill (3 men per shift)	0.010
Yard gang (13 men one shift)	0.015
Repair gang (12 men one shift)	0.023
Packing house	0.040
Miscellaneous	0.002
Total labor	$0.190
Raw Material:	
Coal for quarry and mill	$0.225
Gypsum	0.018
Total raw material	$0.243
Supplies:	
Repair parts	$0.040
Lubricants	0.020
Miscellaneous supplies	0.030
Total supplies	$0.090
Plant Charges:	
Interest	$0.070
Sinking fund	0.050
Depreciation and wear and tear	0.050
Total plant charges	$0.170

General Expense:	
Office force (12 men one shift)	$0.020
Administration and selling	0.065
Total general expense	$0.085
Grand total	$0.778

The above figures multiplied by 1,200 give the daily cost.

There were 4 boilers, each 250 hp., and 2 engines of 500 hp. each. Six kilns were run, two shifts daily.

The fuel for burning clinker was gas slack coal, at $2.60 per ton, requiring 105 lbs. per bbl. of clinker. Under the boilers and in the dryers 75 lbs. of bituminous coal (at $3 per ton) per bbl. of cement.

The mill equipment was of the ball and tube type.

A mill can be built for $50,000 to $60,000 per kiln, exclusive of land. A 1,200-bbl. plant (6 kilns) need not cost more than $420,000 including land. From 30 to 100 acres, at $200 per acre, are commonly used by larger plants than this. Figuring on 11 mos. run, or an annual output of 360,000 bbls., interest at 6% on $420,000 is $25,200 per year, or 7 cts. per bbl.

A 60-ft. kiln costs $3,000, but a 100-ft. kiln can be bought for $5,000, and will do the duty of two 60-ft. kilns at much less expense; 100-ft. kilns have turned out as much as 475 bbls. per day. The Edison Cement Co. uses 150-ft. kilns.

In a well-equipped mill without countershafting, the raw and clinker mills alone use half the horsepower, and of the repair parts fully 75% are required by them, as well as 50% of the lubricants and 66% of the miscellaneous supplies. One-third the cost of a cement mill is in the crushing and pulverizing departments with their necessary buildings and power.

The stone from the quarry is crushed to 2½ to 3-in. size in a No. 5 or 6 gyratory crusher, but a No. 7½ or 8 is much better.

In the 1,200-bbl. mill, three ball mills and three tube mills on the raw side kept the six 60-ft. kilns going even when 1,310 bbls. were turned out per day. The same number of ball and tube mills on the clinker side, however, only averaged 750 bbls. per day, but under better management this was increased to 900 bbls.

Theory of the Quantity of Cement in Mortar and Concrete.—All sand contains a large percentage of voids. In 1 cu. ft. of loose sand there are 0.3 to 0.5 cu. ft. of voids; that is, 30% to 50% of the sand is voids. In making mortar the cement is mixed with sand, and the flour-like grains of the cement fit in between the grains of the sand, occupying a part or all of the voids in the sand. According to the old theory (as given in Trautwine's Pocket-book and elsewhere), the amount of cement required to make a given mortar is calculated as follows: Suppose the mortar is to be 1 cu. ft. of cement to 2 cu. ft. of sand (a 1 to 2 mortar); and suppose the sand contains 35% voids, then 2 cu. ft. of sand would contain 2×0.35; or 0.7 cu. ft. voids. Now, the 1 cu. ft. of cement would fill this 0.7 cu. ft. of voids in the sand and leave an excess of $1 - 0.7$, or 0.3 cu. ft. of cement; hence, the resulting mortar would be 2 cu. ft. of sand + 0.3 cu. ft. of cement (the excess left over after filling the voids in the sand), thus making 2.3 cu. ft.

of mortar from the mixture of 1 cu. ft. of cement with 2 cu. ft. of sand. As above stated, this simple theory was commonly given by all writers (without exception, so far as I know), although many contractors and some engineers must have learned by experience that the theory is incorrect. In 1901, I called public attention to the errors of the theory and published a formula that gives much closer approximations to actual tests.

Since a correct estimate of the number of barrels of cement per cubic yard of mortar or concrete is very important, and since it is not always possible to make actual mixtures before bidding, it seems wise to give space to a discussion of the theory that I have offered.

When loose sand is mixed with water, its volume or bulk is increased, subsequent jarring will decrease its volume, but still leave a net gain of about 10%; that is, 1 cu. ft. of dry sand becomes about 1.1 cu. ft. of damp sand. Not only does this increase in the volume of the sand occur, but, instead of increasing the voids that can be filled with cement, there is an absolute loss in the volume of available voids. This is due to the space occupied by the water necessary to bring the sand to the consistency of mortar; furthermore, there is seldom a perfect mixture of the sand and cement in practice, thus reducing the available voids. It is safe to call this reduction in available voids about 10%.

When loose, dry Portland cement is wetted, it shrinks about 15% in volume, behaving differently from the sand, but it never shrinks back to quite as small a volume as it occupies when packed tightly in a barrel. Since barrels of different brands vary widely in size, the careful engineer or contractor will test any brand he intends using in large quantities, in order to ascertain exactly how much cement paste can be made. He will find a range of from 3.2 cu. ft. to 3.8 cu. ft. per bbl. of Portland cement. Obviously the larger barrel may be cheaper though its price is higher. Specifications often state the number of cubic feet that will be allowed per barrel in mixing the concrete ingredients, so that any rule or formula to be of practical value must contain a factor to allow for the specified size of the barrel, and another factor to allow for the actual number of cubic feet of paste that a barrel will yield—the two being usually quite different.

The deduction of a rational, practical formula for computing the quantity of cement required for a given mixture will now be given, based upon the facts above outlined.

Let p = number of cu. ft. cement paste per bbl., as determined by actual cost.

n = number of cu. ft. of cement per bbl., as specified in the specifications.

s = parts of sand (by volume) to one part of cement, as specified.

g = parts of gravel or broken stone (by volume) to one part of cement, as specified.

v = percentage of voids in the dry sand, as determined by tests

V = percentage of voids in the gravel or stone, as determined by test.

Then, in a mortar of 1 part cement to s parts sand, we have:

$$ns = \text{cu. ft. of dry sand to 1 bbl. cement.}$$

$$nsv = \text{cu. ft. of voids in the dry sand.}$$

$$0.9\,nsv = \text{cu. ft. of available voids in the wet sand.}$$

$$1.1\,ns = \text{cu. ft. of wet sand.}$$

$$p - 0.9\,nsv = \text{cu. ft. of cement paste in excess of the voids.}$$

Therefore:

$$1.1\,ns + (p - 0.9\,nsv) = \text{cu. ft. of mortar per bbl.}$$

Therefore:

$$N = \frac{27}{1.1\,ns + (p - 0.9\,nsv)} = \frac{27}{p + ns\,(1.1 - 0.9\,v.)}$$

N being the number of barrels of cement per cu. yd. of mortar.

When the mortar is made so lean that there is not enough cement paste to fill the voids in the sand, the formula becomes

$$N = \frac{27}{1.1\,ns}$$

A similar line of reasoning will give us a rational formula for determining the quantity of cement in concrete; but there is one point of difference between sand and gravel (or broken stone), namely, that the gravel does not swell materially in volume when mixed with water. However, a certain amount of water is required to wet the surface of the pebbles, and this water reduces the available voids, that is, the voids that can be filled by the mortar. With this in mind, the following deduction is clear, using the nomenclature and symbols above given:

ng = cu. ft. of dry gravel (or stone).

ngV = cu. ft. of voids in dry gravel.

$0.9\,ngV$ = cu. ft. of "available voids" in the wet gravel.

$p + ns\,(1.1 - 0.9\,v) - 0.09\,ngV$ = excess of mortar over the available voids in the wet gravel.

$ng + p + ns\,(1.1 - 0.9\,v) - 0.9\,ngV$ = cu. ft. of concrete from 1 bbl. cement.

$$N = \frac{27}{p + ns\,(1.1 - 0.9\,v) + ng\,(1 - 0.9\,V)}$$

N being the number of barrels of cement required to make 1 cu. yd. of concrete.

This formula is rational and perfectly general. Other experimenters may find it desirable to use constants slightly different from the 1.1 and the 0.9, for fine sands swell more than coarse sands, and hold more water.

The reader must bear in mind that when the voids in the sand

exceed the cement paste, and when the available voids in the gravel (or stone) exceed the mortar, the formula becomes:

$$N = \frac{27}{ng}$$

These formulas give the amounts of cement in mortars and concretes compacted in place. Tables I to IV are based upon the foregoing theory, and will be found to check satisfactorily with actual tests.

TABLE I. BARRELS OF PORTLAND CEMENT PER CUBIC YARD OF MORTAR. (Voids in sand being 35%, and 1 bbl. cement yielding 3.65 cu. ft. of cement paste.)

Proportion of Cement to Sand.	1 to 1	1 to 1½	1 to 2	1 to 2½	1 to 3	1 to 4
	Bbls.	Bbls.	Bbls.	Bbls.	Bbls.	Bbls.
Barrel specified to be 3.5 cu. ft.	4.22	3.49	2.97	2.57	2.28	1.76
" " 3.8 "	4.09	3.33	2.81	2.45	2.16	1.62
" " 4.0 "	4.00	3.24	2.73	2.36	2.08	1.54
" " 4.4 "	3.81	3.07	2.57	2.27	2.00	1.40
Cu. yds. sand per cu. yd. mortar	0.6	0.7	0.8	0.9	1.0	1.0

TABLE II. BARRELS OF PORTLAND CEMENT PER CUBIC YARD OF MORTAR. (Voids in sand being 45%, and 1 bbl. cement yielding 3.4 cu. ft. of cement paste.)

Proportion of Cement to Sand.	1 to 1	1 to 1½	1 to 2	1 to 2½	1 to 3	1 to 4
	Bbls.	Bbls.	Bbls.	Bbls.	Bbls.	Bbls.
Barrel specified to be 3.5 cu. ft.	4.62	3.80	3.25	2.84	2.35	1.76
" " 3.8 "	4.32	3.61	3.10	2.72	2.16	1.62
" " 4.0 "	4.19	3.46	3.00	2.64	2.05	1.54
" " 4.4 "	3.94	3.34	2.90	2.57	1.86	1.40
Cu. yds. sand per cu. yd. mortar	0.6	0.8	0.9	1.0	1.0	1.0

In using these tables remember that the proportion of cement to sand is by volume, and not by weight. If the specifications state that a barrel of cement shall be considered to hold 4 cu. ft., for example, and that the mortar shall be 1 part cement to 2 parts sand, then 1 barrel of cement is mixed with 8 cu. ft. of sand, regardless of what is the actual size of the barrel, and regardles of how much cement paste can be made with a barrel of cement. If the specifications fail to state what the size of a barrel will be, then the contractor is left to guess.

If the specifications call for proportions by weight, assume a Portland barrel to contain 380 lbs. of cement, and test the actual weight of a cubic foot of the sand to be used. Sand varies extremely in weight, due both to the variation in the per cent of voids, and to the variation in the kind of minerals of which the sand is composed. A quartz sand having 35% voids weighs 107 lbs. per cu. ft.; but a quartz sand having 45% voids weighs only 91 lbs. per cu. ft. If the weight of the sand must be guessed at, assume 100 lbs. per cu. ft. If the specifications require a mixture of 1 cement to 2 of sand by weight, we will have 380 lbs. (or 1 bbl.) of cement mixed with 2 × 380, or 760 lbs. of sand; and if the sand weighs 90 lbs. per cu. ft., we shall have 760 ÷ 90, or 8.44 cu. ft. of sand to

every barrel of cement. In order to use the tables above given, we may specify our own size of barrel; let us say 4 cu. ft.; then 8.44 ÷ 4 gives 2.11 parts of sand by volume to 1 part of cement. Without material error we may call this a 1 to 2 mortar, and use the tables, remembering that our barrel is now "specified to be" 4 cu. ft. If we have a brand of cement that yields 3.4 cu. ft. of paste per bbl., and sand having 45% voids, we find that approximately 3 bbls. of cement per cu. yd. of mortar will be required.

It should be evident from the foregoing discussions that no table can be made, and no rule can be formulated that will yield accurate results unless the brand of cement is tested and the percentage of voids in the sand determined. This being so the sensible plan is to use the tables merely as a rough guide, and, where the quantity of cement to be used is very large, to make a few batches of mortar using the available brands of cement and sand in the proportions specified. Ten dollars spent in this way may save a thousand, even on a comparatively small job, by showing what cement and sand to select.

TABLE III. INGREDIENTS IN 1 CUBIC YARD OF CONCRETE.

(Sand voids, 40%; stone voids, 45%; Portland cement barrel yielding 3.65 cu. ft. paste. Barrel specified to be 3.8 cu. ft.)

Proportions by Volume.	1:2:4	1:2:5	1:2:6	1:2½:5	1:2½:6	1:3:4
Bbls. cement per cu. yd. concrete	1.46	1.30	1.18	1.13	1.00	1.25
Cu. yds. sand per cu. yd. concrete	0.41	0.36	0.33	0.40	0.35	0.53
Cu. yds. stone per cu. yd. concrete	0.82	0.90	1.00	0.80	0.84	0.71
Proportions by Volume	**1:3:5**	**1:3:6**	**1:3:7**	**1:4:7**	**1:4:8**	**1:4:9**
Bbls. cement per cu. yd. concrete	1.13	1.05	0.96	0.82	0.77	0.73
Cu. yds. sand per cu. yd. concrete	0.48	0.44	0.40	0.46	0.43	0.41
Cu. yds. stone per cu. yd. concrete	0.80	0.88	0.93	0.80	0.86	0.92

Note.—This table is to be used where cement is measured packed in the barrel for the ordinary barrel holds 3.8 cu. ft.

It will be seen that the above table can be condensed into the following rule:

Add together the number of parts and divide this sum into ten, the quotient will be approximately the number of barrels of cement per cubic yard.

Thus for a 1 : 2 : 5 concrete, the sum of the parts is 1 + 2 + 5, which is 8; then 10 ÷ 8 is 1.25 bbls., which is approximately equal to the 1.30 bbls. given in the table. Neither this rule nor this table is applicable if a different size of cement barrel is specified, or if the voids in the sand or stone differ materially from 40% and 45% respectively. There are such inumerable combinations of varying voids, and varying sizes of barrel, that the author does not deem it worth while to give other tables.

TABLE IV. INGREDIENTS IN 1 CUBIC YARD OF CONCRETE.

(Sand voids, 40%; stone voids, 45%; Portland cement barrel yielding 3.65 cu. ft. of paste. Barrel specified to be 4.4 cu. ft.)

Proportions by Volume.	1:2:4	1:2:5	1:2:6	1:2½:5	1:2½:6	1:3:4
Bbls. cement per cu. yd. concrete	1.30	1.16	1.00	1.07	0.96	1.08
Cu. yds. sand per cu. yd. concrete	0.42	0.38	0.33	0.44	0.40	0.53
Cu. yds. stone per cu. yd. concrete	0.84	0.95	1.00	0.88	0.95	0.71

Proportions by Volume.	1:3:5	1:3:6	1:3:7	1:4:7	1:4:8	1:4:9
Bbls. cement per cu. yd. concrete	0.96	0.90	0.82	0.75	0.68	0.64
Cu. yds. sand per cu. yd. concrete	0.47	0.44	0.40	0.49	0.44	0.42
Cu. yds. stone per cu. yd. concrete	0.78	0.88	0.93	0.86	0.88	0.95

NOTE.—This table is to be used when the cement is measured loose, after dumping it into a box for under such conditions a barrel of cement yields 4.4 cu. ft. of loose cement.

CEMENT PER CUBIC YARD OF MORTAR BY TEST.

According to tests by Sabin, by Fuller (in Taylor and Thompson) and by H. P. Boardman, the following results were obtained:

Authority.	Neat. Bbls.	1:1. Bbls.	1:2. Bbls.	1:3. Bbls.	1:4. Bbls.	1:5. Bbls.	1:6. Bbls.	1:7. Bbls.	1:8. Bbls.
Sabin	7.40	4.17	2.84	2.06	1.62	1.33	1.14	....	....
W. G. Fuller	8.02	4.58	3.09	2.30	1.80	1.48	1.23	1.11	1.00
H. P. Boardman	7.40	4.50	3.18	2.35	....	....	....	....	....

The proportions were by barrels of cement to barrels of sand, and Sabin called a 380-lb. barrel 3.65 cu. ft., whereas Fuller called a 380-lb. barrel 3.80 cu. ft.; and Boardman called a 380 lb. barrel 3.5 cu. ft. Sabin used a sand having 38% voids; Fuller used a sand having 45% voids; and Boardman used a sand having 38% voids. It will be seen that the cement used by Sabin yielded 3.65 cu. ft. of cement paste per bbl. (i. e. 27 ÷ 7.4), whereas the (Atlas) cement used by Fuller yielded 3.4 cu. ft. of cement paste per bbl. Sabin found that a barrel of cement measured 4.37 cu. ft. when dumped and measured loose.

Mr. Boardman states a barrel (280 lbs., net) of Lehigh Portland cement yields 3.65 cu. ft. of cement paste; and that a barrel (265 lbs., net) of Louisville natural cement yields 3.0 cu. ft. of cement paste.

Mr. J. J. R. Croes, M. Am. Soc. C. E., states that 1 bbl. of Rosendale cement and 2 bbls. of sand (8 cu. ft.) make 9.7 cu. ft. of mortar, the extreme variations from this average being 7%.

The Size and Weight of Barrels of Cement.—A barrel of Portland cement contains 380 lbs. of cement, and the barrel itself weighs 20 lbs. more. The size of the barrel varies considerably, due to the difference in weight per struck bushel, and to the difference in compressing the cement in the barrel. A light burned Portland cement weighs 100 lbs. per struck bushel; a heavy burned cement weighs 118 to 125 lbs. per struck bushel. The number of cubic feet of packed Portland cement in a barrel ranges from 3 to 3½. English Portland cement barrels contain 3⅓ to 3½ cu. ft.

packed. There are usually four bags (cloth sacks) of cement to the barrel, and each bag itself weighs 1⅛ lbs.

The natural cements are lighter than Portland. The Western cements, such as Louisville, Akron and Utica weigh 265 lbs. per bbl., and the barrel weighs 15 lbs. more. A barrel of Louisville cement = 3¾ cu. ft. packed. The Rosendale cements of New York and Pennsylvania weigh 300 lbs. per bbl. and the barrel weighs 20 lbs. more. There are usually three bags of natural cement to the barrel.

When cement is ordered in cloth sacks, there is a charge made of 10 cts. per sack, but on return of the sacks a credit of 8 to 10 cts. per sack is allowed. Cement ordered in wooden barrels costs 10 cts. more per bbl. than in bulk. Cement ordered in paper bags costs 5 cts. more per bbl. than in bulk. Hence it is that nearly all cement used in large quantities is ordered in cloth sacks which are returned.

When a barrel of cement is dumped out and shoveled into a box it measures much more than when packed in the barrel, ordinarily from 20 to 30% more. I have measured a number of barrels of English Portland cement, which is still much used on the Pacific Coast of America, and find that a barrel having a capacity of 3¾ cu. ft. between heads will yield 4.5 cu. ft. of cement measured dry and loose in a box. I have found brands of American Portland cement that yield 4.65 cu. ft. when measured loose in a box. The variation is considerable, as is seen in the following table, compiled from data given by Mr. Howard Carson, M. Am. Soc. C. E.:

Brand of Portland cement.	(1) Capacity of bbl. Cu. ft.	(2) Actual contents of packed bbl. Cu. ft.	(3) Volume when dumped loose. Cu. ft.	Increase in bulk.
Giant	3.5	3.35	4.17	25%
Atlas	3.45	3.21	3.75	18%
Saylor's	3.25	3.15	4.05	30%
Alsen (German)	3.22	3.16	4.19	33%
Dyckerhoff (German)	3.12	3.03	4.00	33%

Some engineers require the contractor to measure the sand and stone in the same sized barrel that the cement comes in; then 1 part of sand or stone usually means 3⅛ cu. ft. Other engineers permit both heads of the barrel to be knocked out, for convenience in measuring the sand and stone; then a barrel means about 3¾ cu. ft. Still other engineers permit the contractor to measure his cement in a box loose: then a barrel usually means from 4 to 4.5 cu. ft. Since most of the cement now used is shipped in bags and since four bags of Portland cement make a barrel, it is the custom among most engineers to call a bag 1 cu. ft., even though it may yield a little more cement. Still other engineers prefer to specify that a Portland barrel shall be called 3.8 cu. ft., which is equivalent to 100 lbs. of cement per cu. ft.

It is desirable that engineers and architects adopt some uniform practice in this matter, for now a contractor is often unable to estimate the quantity of cement required for any specified mixture because the size of the barrel is not specified.

There have been advocates of proportioning parts by weight, but, aside from the fact that it is seldom convenient to weigh the ingredients of every batch, there is no gain in such a departure from long-standing precedent. Sand and gravel and stone are by no means constant in specific gravity, as advocates of weighing seem to suppose.

Effect of Moisture on Voids in Sand.—Few engineers and fewer contractors realize how greatly the volume of sand is affected by the presence of varying percentages of moisture in the sand. A dry, loose sand that has 45% voids if mixed with 5% (by weight) of water will swell (unless tamped) to such an extent that its voids may be 57%. The same sand if saturated with more water until it becomes a thin paste, may show only 37½% voids after the sand has settled. The following tests by Feret show the effect that water has upon sand:

Two kinds of sand were used, a very fine sand and a coarse sand. They were measured in a box that held 2 cu. ft. and was 8 ins. deep, the sand being shoveled into the box, but not tamped or shaken. After measuring and weighing the dry sand, 0.5% (by weight) of water was added, the sand was mixed and shoveled into the box again and weighed. This was repeated with varying percentages of water, up to 10%, with the following results:

Per cent of water in sand.	0%	0.5%	1%	2%	3%	5%	10%
	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
Weight per cu. yd. of fine sand and water....	3,457	2,206	2,085	2,044	2,037	2,035	2,133
Weight per cu. yd. of coarse sand and water.	2,551	2,466	2,380	2,122	2,058	2,070	2,200

It will be noted that the weight of mixed sand and water is given; but, to ascertain the exact weight of dry sand in the mixture, divide the weight given in the table by 100% plus the given tabular per cent; thus, the weight of dry fine sand mixed with 5% of water is $2{,}035 \div 1.05 = 1{,}938$ lbs. per cu. yd. It will also be noted that when the water exceeds 3 to 5%, the weight of the mixture increases, showing that a larger percentage of water compacts the sand. The voids in the dry fine sand were 45%, and in the sand with 5% moisture they were 56.7%.

It is well known that pouring water onto loose, dry sand compacts it. By mixing fine sand and water to a thin paste, pouring it into a pail and allowing it to settle, it was found that the sand occupied 11% less space than when measured dry in a box. The voids in fine sand, having a specific gravity of 2.65, were determined by measurements in a quart measure, and found to be as follows:

	Voids.
Sand, not packed	44½%
Sand, shaken to refusal......................	35 %
Sand, saturated with water..................	37½%

Mr. H. P. Boardman made some experiments with Chicago sand having 34 to 40% voids when dry, by adding water to the sand. The results were as follows:

	%	%	%	%	%
Water added, % by weight....	2	4	6	8	10
Resulting increase in volume..	17.6	22	19.5	16.6	15.6

However, a very moderate amount of shaking would reduce this increase in volume by 1/3 to 1/2.

Effect of Size of Sand Grains on Voids.—If in any given volume of sand all the grains were of the same shape and of uniform size, the percentage of voids would be the same regardless of the size of the grains. This is equivalent to saying that the finest birdshot has the same percentage of voids as the coarsest buckshot. Natural sand grains, unless they have been sorted by screening, are apt to vary greatly in size, large and small being intermixed. It is this that causes such wide discrepancies in published data as to the percentage of voids in dry bank sands. We may divide sand into three sizes, for convenience. The largest size (L) being sand that will pass a sieve of 5 meshes per lineal inch, but will not pass a sieve of 15 meshes per lineal inch; the medium size (M) being sand that will pass a 15-mesh sieve, but will not pass a sieve of 50 meshes per lineal inch; and the fine size (F) being sand tnat will ass a 50-mesh sieve. If we mix varying proportions of the large, medium and fine (L, M and F), we find that we get the densest mixture, with the least voids, when we have an L6, M0, F4 mixture, that is, 6 parts large size, no parts medium, and 4 parts fine size. With a dry sand whose grains have a specific gravity of 2.65, if we weigh a cubic yard of either the fine, or the medium, or the large size, we find a weight of 2,190 lbs. per cu. yd., which is equivalent to 51% voids. If we mix the three different sizes in varying proportions, we find, as above stated, that an L6, M0, F4 mixture is densest, and it weighs 2,840 lbs. per cu. yd. shoveled into a box dry. This is equivalent to 36% voids. We can get a denser mixture, with a lower percentage of voids, if we mix about equal parts of sand and clean gravel. It will be noted that the common statement that the densest mixture is obtained by a mixture of gradually increasing sizes of grains is erroneous. There must be enough difference in the sizes of grains to provide voids so large that the smaller grains will enter them and not wedge the larger grains apart.

The shape of the grains has a very pronounced effect upon the percentage of voids, rounded grains having less voids than angular grains. Using sand having a granulometric composition of L5, M3, F2, measured in a quart measure, the following results were obtained by Feret:

	Voids. Unshaken.	Voids. Shaken.
Natural sand, rounded grains............	35.9%	25.6%
Crushed quartzite angular grains.........	42.1	27.4
Crushed shells, flat grains................	44.3	31.8
Residue of quartzite, flat grains..........	47.5	34.6

The measure was shaken until no further settlement could be produced.

Mr. William B. Fuller made the following tests: A dry sand, having 34% voids shrank 9.6% in volume upon thorough tamping,

until it had 27% voids. The same sand moistened with 6% water, and loose, had 44% voids, which was reduced to 31% by ramming. The same sand saturated with water had 33% voids, and by thorough ramming its volume was reduced 8½%, until the sand had only 26½% voids.

TABLE V.—SIZES OF SAND GRAINS.

Held by a Sieve.	A.	B.	C.	E.
No. 10	35.3%	....	....	....
No. 20	32.1	12.8%	4.2%	11%
No. 30	14.6	49.0	12.5	14
No. 40	....	....	44.4	....
No. 50	9.6	29.3	....	53
No. 100	4.9	5.7	....	....
No. 200	2.0	2.3	....	....
Voids	33%	39%	41.7%	31%

Note.—A is a "fine gravel" (containing 8% clay) used at Philadelphia. B. Delaware River sand. C. St. Mary's River sand. D. Green River, Ky., sand, "clean and sharp."

TABLE VI.—VOIDS IN SAND.

Locality.	Authority.	Voids.	Remarks.
Ohio River	W. M. Hall	31%	Washed
Sandusky, O.......	C. E. Sherman	40%	Lake
Franklin Co., O....	C. E. Sherman	40%	Bank
Sandusky Bay, O...	S. B. Newberry	32.3%	....
St. Louis, Mo......	H. H. Henby	34.3%	Miss. River
Sault Ste. Marie....	H. von Schon	41.7%	River
Chicago, Ill.	H. P. Boardman	34 to 40%	....
Philadelphia, Pa....	....	39%	Del. River
Mass. Coast.......	....	31 to 34%	....
Boston, Mass.	Geo. A. Kimball	33%	Clean
Cow Bay, L. I......	Myron S. Falk	40½%	....
Little Falls, N. J...	W. B. Fuller	45.6%	....
Canton, Ill.........	G. W. Chandler	30%	Clean

Voids and Weight of Broken Stone and Gravel.—Data as to these will be found in Section III, Rock Excavation. Consult the index under "Broken Stone," also under "Gravel."

Tables for Estimating the Cost of Concrete and for Designing Reinforced Concrete Beams and Slabs.[*]—Tables of cost and crushing strength of concrete mixtures, when compiled from reliable

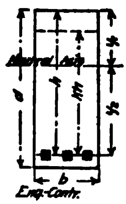


Fig. 1.

data, have a very useful purpose in figuring on concrete work. In our issue of Feb. 19, 1908, we published a table of this character long used by a prominent Eastern contractor. Another table of

[*]*Engineering-Contracting*, Aug. 26, 1908.

TABLE VII.—QUANTITIES, COST AND STRENGTH OF CONCRETE.

Ratio of Volume of: Cement	Sand	Stone	Materials for 1 cu. yd. Rammed Concrete — Broken Stone Screened to Uniform Size: Cem.—Bbl.	Sand—Cu. yd.	Stone—Cu. yd.	Average Condit'n Broken Stone Dust Screened Out: Cem.—Bbl.	Sand—Cu. yd.	Stone—Cu. yd.	For Gravel or Mixed Stone and Gravel: Cem.—Bbl.	Sand—Cu. yd.	Gravel—Cu. yd.	Av. volume of a batch in place using 1 bbl. cem. (3.8 cu. ft.)	Cost per cu. ft. of concrete in place: Broken Stone.	Clean Gravel.	Ultimate Compressive strength stone concrete 6-in. cubes 1 month old in lbs. per sq. in.	Ratio of strength of concretes based on 1:2½:5 mix.
1	½	1	....	...	...	....	...	...	....	...	...	6.8 cu. ft.	$0.37	$0.34	5,540	2.41
1	1	2	2.85	.40	.80	2.73	.38	.77	2.62	.37	.74	9.7 cu. ft.	0.314	0.274	4,000	1.73
1	½	3	2.09	.44	.88	2.00	.42	.84	1.91	.40	.81	13.0 cu. ft.	0.283	0.237	3,200	1.39
1	2	4	1.65	.46	.93	1.57	.44	.88	1.50	.42	.84	16.5 cu. ft.	0.264	0.214	2,700	1.17
1	2½	5	1.37	.48	.96	1.30	.46	.92	1.24	.44	.87	20.0 cu. ft.	0.246	0.195	2,300	1.00
1	3	6	1.16	.49	.98	1.11	.47	.94	1.05	.44	.89	24.0 cu. ft.	0.230	0.179	2,000	.87
1	4	8	0.90	.51	1.01	0.85	.48	.96	0.81	.46	.91	31.0 cu. ft.	0.210	0.160	1,625	.70
1	5	10	0.73	.52	1.03	0.69	.49	.97	0.66	.46	.93	38.0 cu. ft.	0.200	0.149	1,400	.61
1	6	12	0.62	.52	1.04	0.58	.49	.98	0.56	.47	.94	46.0 cu. ft.	0.192	0.141	1,250	.54

Notes.—Water required = 15% to 25% (by volume of concrete). Strength of Concrete is directly proportional to amount of cement used. Machine mixing averages (on strength tests of product) 20% better than hand mixing. Costs based on following constants: Cement, delivered, per bbl. (net), $1.75; sand, delivered, per cu. yd., $1.20; broken stone, delivered, per cu. yd., $1.90; gravel, delivered, per cu. yd., $1.15; labor, per cu. yd., $1.62. Average costs, machine mixing, $1.00 per cu. yd. in place. Hand mixing, $1.50 per cu. yd. in place. Safe stress on concrete: Working stress on beam, ultimate, 4.5; working stress in columns, ultimate, 6. Concrete weighs 140 lbs. per cu. ft.ft.

similar scope is given here (Table VII). This table has been compiled by Mr. H. J. Fixmer, Assistant Engineer, Board of Local Improvements, Chicago, Ill., from various and it is believed trustworthy sources. The cost column, while necessarily based on given constants, shows relative costs of different mixtures which are fairly true for all cases. These costs, in connection with the ratio of strength figures, show almost at a glance the economy of the selected mixtures.

Table VIII is used in designing slabs and girders. Attention is called to the fact that the value *h* is used and that the value *d-h* is the selected thickness of the fireproofing only. In other words the depth of the beam is the value *h* plus the thickness required for fireproofing. The value *fc*—500 lbs.—is practically the universal building code allowance. The value *fs* of course varies with the percentage of steel used. A little study of the table shows the advantage of using not less than 1⅛% of steel for reinforcing.

For purposes of comparison the following data as to brickwork are useful:

	Crushing strength lbs. per sq. in.	Cost per cu. ft.
First-class brickwork in cement mortar......	834	$0.44
Good brick in cement mortar................	486	0.35
Ordinary brick in lime mortar..............	347	0.26

1,000 brick = 40 cu. ft. when laid.

Percentage of Water Required in Mortar.—A good rule by which to determine the percentage of water by weight for any given mixture of mortar is as follows: Multiply the parts of sand by 8, add 24 to the product and divide the total by the sum of the parts of sand and cement.

Example: Required percentage of water for a mortar of 1 cement to 3 sand:

SOLUTION.

1 cement	= 24%
3 sand × 8%	= 24%
4 parts at 12%	= 48%

Hence the water should be 12% of the combined weight of the cement and sand. For a 1:1 mortar, the rule gives 16% water. For 1:2 mortar the rule gives 13⅓% water. For a 1:6 mortar the rule gives 10.3% water. Incidentally, it may be added, the percentages of water obtained by this rule give a mortar that has the greatest adhesion to steel rods (see Falk's "Cements, Mortars and Concretes," page 61).

About 23 gals of water are required per cu. yd. of 1:3:6 concrete.

Estimating the Cost of Steel in Reinforced Concrete.—In reinforced concrete the amount of steel is usually expressed in percentages of the volume of concrete. Thus 1% of steel means that one one-hundredth part of the volume of reinforced concrete is steel. In a cubic yard of reinforced concrete there is 1% of 27 cu. ft., or 0.27 cu. ft. of steel, if the reinforcement is 1%. A cubic foot of steel weighs 490 lbs., but for all practical purposes we can call it 500 lbs.

TABLE VIII.—REINFORCED CONCRETE BEAM AND SLAB TABLE.

(Table based on a 1 : 2½ : 5 mix concrete (1 month old) wherein $\frac{Es}{Eo} = \frac{30,000,000}{2,500,000} = 12$. $fo = 500$ lbs. per sq. in. $fs = \frac{1}{3}$ (or ¼) elastic limit of steel in lbs. per sq. in.)

fc = Unit Work'g Stress in Concrete.	fs = Unit Work'g Stress in Steel.	Dimensions in Fig. 1. Y1.	Y2.	K.	Mo = Resisting Moment in inch lbs.	As = Area of Steel in sq. ins.	P = Per cent of Steel.	Reinforcing. Diam. of Bars.	Area in sq. ins. Square.	Round.
500	20,000	0.23	0.77	0.93	55.8 bh^2	.0030bh	30/100%	⅛ in.	.017	.012
500	16,000	0.27	0.73	0.91	61.15bh^2	.0042bh	42/100%	¼ in.	.067	.049
500	14,000	0.30	0.70	0.90	68.05bh^2	.0054bh	54/100%	⅜ in.	0.14	0.11
500	12,000	0.33	0.67	0.89	73.68bh^2	.0069bh	69/100%	½ in.	0.25	.196
500	10,000	0.37	0.63	0.87	80.05bh^2	.0092bh	92/100%	⅝ in.	0.39	.307
500	8,000	0.43	0.57	0.85	91.12bh^2	.0134bh	1 34/100%	¾ in.	0.60	.442
500	6,000	0.50	0.50	0.83	103.6 bh^2	.0208bh	2 08/100%	⅞ in.	.765	.600
500	4,000	0.60	0.40	0.80	120.0 bh^2	.0375bh	3¾%	1 in.	1.00	.785
								1¼ in.	1.56	1.23
								1½ in.	2.25	1.765

Notes.—$Mo.$ = Resisting Moment, = $Kh\,As\,fs$. $d - h$ = (for fireproofing) = ¾ in. to 2½ in. $B. M.$ = Bending Moment. For Uniform Load = $\frac{Wl}{8}$. W = Total Weight incl. w't of Concrete. l = span in ins. Working Stress, Shear, = 75 lbs. per sq. in. Working Stress, Adhesion, = 75 lbs. per sq. in. 1 34/100% Steel (32,000/4 = 8,000 lbs. stress) or greater per cent gives most economical reinf.

Remarks.—Steel weighs 3⅓ times the weight of Concrete. Steel at 2½ cts. per lb. costs (av.) 50 times cost of Concrete. Sectional area of bars in sq. ins. times 3.4 gives the weight of bars in lbs. per lineal foot. Cost of placing Steel ranges from ⅛ ct. to ½ ct. per lb. Use $fc = 500$ lbs. and 1 : 2½ : 5 mix for ordinary work. Use richer mix when using factor of safety greater than 4.

Hence reinforced concrete containing 1% of steel has 0.27 × 500 = 135 lbs. of steel per cu. yd.

Per cent. of Steel.	Lbs. of Steel Per Cu. Ft.	Lbs. of Steel Per Cu. Yd.
0.20	1.00	27.0
0.20	1.25	33.8
0.30	1.50	40.5
0.35	1.75	47.3
0.40	2.00	54.0
0.45	2.25	60.8
0.50	2.50	67.5
0.55	2.75	74.3
0.60	3.00	81.0
0.65	3.25	87.8
0.70	3.50	94.5
0.75	3.75	101.3
0.80	4.00	108.0
0.85	4.25	114.8
0.90	4.50	121.5
0.95	4.75	128.3
1.00	5.00	135.0

Knowing the price of steel for reinforcing, it is a simple matter of multiplication to estimate the cost of the steel for any percentage of reinforcement. For example it is desired to know the cost of steel for a concrete sewer reinforced with twisted bars ⅜-in. square, the steel amounting to 0.30%. According to the table there would be 40.5 lbs. of steel per cu. yd. in concrete reinforced with 0.30% of steel. The following table of prices is given in a catalog of Ransome's in 1906:

PRICE OF RANSOME TWISTED STEEL BARS.

Add the prices given below to the prevailing prices for plain steel bars f. o. b. Pittsburg.

	Per 100 lbs.
Larger than ¾ inch square add	0.30
Larger than 11/16 inch square add	0.375
Larger than ⅝ inch square add	0.375
Larger than 9/16 inch square add	0.425
Larger than ½ inch square add	0.425
Larger than 7/16 inch square add	0.65
Larger than ⅜ inch square add	0.70
Larger than 5/16 inch square add	0.75
Larger than ¼ inch square add	0.80
Larger than ¼x1 inch add	0.425
Larger than ⅛x⅛ inch add	1.20

The above figures are for carload lots. For quantities less than carload lots, add $0.05 per 100 lbs. For quantities less, between 1,000 lbs. and 2,000 lbs., add $0.10 per 100 lbs.

For quantities less than 1,000 lbs., add $0.30 per 100 lbs.

If the present price of plain steel bars is $1.50 per 100 lbs., f. o. b. Pittsburg, then the price of ⅜-in. Ransome twisted steel bars is $1.50 + $0.70, or $2.20 per 100 lbs., or 2.2 cts. per lb. f. o. b. Pittsburg. Let us assume that the freight and haulage brings the price up to 2½ cts. per lb., delivered on the job. The labor cost of bending and placing steel in reinforced concrete sewers averages about ½ ct. per lb. Hence the total cost of the steel in place is 3 cts. per

lb. in this particular case. Since there are 40½ lbs. of steel per cu. yd. of concrete containing 0.30% steel, we have a total cost of 40.5 × 3 cts. = $1.22 per cu. yd. for the steel.

In like manner all similar problems may be solved. To facilitate rapid estimates, it is a good plan to keep records of all reinforced concrete structures in such form as to show the percentage of steel used. In doing this, however, be careful to separate the foundations which are not reinforced from the superstructure which is reinforced. A reinforced concrete arch bridge usually rests on abutments which are not reinforced. Do not lump together all the concrete in making an estimate, but separate the arch from the abutments. Frequently engineers have failed to separate the yardage of foundation from the yardage of superstructure of reinforced concrete bridges, yet without such a separation accurate cost estimates are impossible.

Cost of Sand.—The cost of sand may be estimated by adding together the cost of loading in the pit, the cost of hauling in wagons, the cost of freight and rehandling if necessary and the cost of washing. On page 553 are given data on the cost of shoveling sand into wagons. The cost of wagon hauling is given on page 125. Freight rates can always be secured, and it is usually safe to estimate the weight on a basis of 2,700 lbs. per cu. yd., provided the sand has not been rained upon after loading in the car. The cost of screening sand by hand is the cost of shoveling it up against an inclined screen; but if a large amount of gravel must be screened to get a small amount of sand, care must be taken to make tests in the pit to ascertain how many cubic feet of gravel and sand must be shoveled to secure one cubic foot of sand. In some places sand must be dredged or pumped with a sand pump from the bottom of a river or lake. In other places sand must be made by crushing stone and running the small crushed product through rolls. At Coudersport, Pa., a small plant for making artificial sand from stone has been in operation for many years.

Stone was crushed and passed through rolls in order to make a sand for the mortar used in the Lanchensee Dam, Germany. A jaw crusher, driven by a 15-hp. engine, crushed 65 cu. yds. of stone (graywacke) per 10-hr. day. All pieces from 0.16 to 1.6 ins. diameter were passed through rolls. The rolls were 14½ ins. long and 34 ins. diameter, and made 22 revolutions per minute, requiring 12 to 15 hp. A pair of these rolls produced 20 cu. yds. of sand per 10-hr. day. The rolls had chilled bands which, when worn, were ground true with an emery wheel without removing the rolls.

Where a large amount of concrete is to be made, a contractor can seldom afford to guess at the source of his sand supply. I have known several instances where long hauls over poor roads have made the sand more expensive than the stone per cubic yard of concrete. Each job should be estimated in detail, using the data given elsewhere in this book.

A very common price for sand in cities is $1 per cu. yd., delivered at the work. Sand is often sold by the load, instead of by the cubic

yard. It is wise to have a written agreement defining the size of a load.

Cost of Washing Sand in a Tank Washer.—Mr. W. H. Roper gives the following data on the cost of washing sand for U. S. Lock No. 3, at Springdale, Pa. The sand dredged from the river contained much fine coal and silt which was removed by the washer, which consisted of a circular tank, 9 ft. diam. x 7 ft. high, provided with a sloping false bottom perforated with 1-in. holes, through which water was forced. A 7½ x 5 x 6-in. pump with a 3-in. discharge pipe was used to force the water into the tank. The paddles for keeping the sand in suspension were rotated by a 7-hp. engine. A charge of 14 cu. yds. of sand was washed in from 1 to 2 hrs., at a cost of 7 cts. per cu. yd. This device was designed by Capt. W. R. Graham, who is said to have applied for a patent. It is doubtful whether any patentable combination exists in the device. See Gillette and Hill's "Concrete Construction" for the design of this washer, and also for the design of the one described in the next paragraph.

Mr. F. H. Stephenson gives the following data relating to a sand washer designed by Mr. Allen Hazen, which consisted of a wooden box 10 ft. long, 2½ ft. wide and 2½ ft. deep; a 6-in. pipe, provided with a gate, or valve, enters at one end, and connects with three 3-in. pipes capped at the ends. In the bottoms of these 3-in. pipes are ½-in. holes, spaced 6 ins. apart, through which water discharges under pressure into the box. Sand is shoveled into the box at one end, and the upward currents of water raise the fine and dirty particles until they escape through the waste troughs. When the box becomes filled with sand a sliding door is raised at the end, and the clean sand flows out through a 3-in. hole in the box. The operation is continuous, so long as sand is fed into the washer. By manipulating the door the sand can be made to flow out with a very small percentage of water. Sand containing 7% of dirt was thus washed so that it contained only 0.6% dirt. In 10 hrs. the washer handled 200 cu. yds. of sand.

If sand is handled to and from the washers by shovels the cost of shoveling is the largest item of expense, and this can be easily estimated. If the sand is dumped into bins which feed into the washer by gravity, and is finally delivered by gravity to buckets or cars, the cost of washing is mainly the cost of pumping, plus the interest and depreciation of plant. The amount of water required per cubic yard has been given above, so that a close estimate of cost can readily be made for any given condition.

Other data as to methods and costs of washing sand and gravel will be found in "Concrete Construction—Methods and Cost" by Gillette and Hill.

Cost of Washing Sand With a Hose.—Where the quantity of sand to be washed is not very large, the simplest method is to use water from a hose. Build a tank 8 ft. wide and 15 ft. long, the bottom having a slope of about 8 ins. in the 15 ft. The sides should be about 8 ins. high at the lower end, rising gradually to 3 ft., the

height of the upper end. The lower end of this tank should be closed with a board gate about 6 ins. high, sliding in guides so that it can be removed. Dump about 3 cu. yds. of the dirty sand at the upper end of the platform and play a stream of water upon it from a ¾-in. nozzle, the man standing on the outside of the lower end of the platform. The water and sand flow down the platform and the dirt passes off with the overflow water over the gate. In about an hour the batch of sand will be washed. By building a pair of platforms the washing can proceed continuously; and one man can wash 30 cu. yds. a day, at a cost of 5 cts. per cu. yd. for his labor. To this must be added the cost of shoveling up the sand again, say, 10 cts. per cu. yd., and any extra hauling due to the location of the washer. If the water is pumped, about 10 cts. more per cu. yd. will be spent for coal and wages, making a total of 25 cts. per cu. yd.

Washing With Sand Ejectors.—Where very large quantities of sand are to be washed more expensive apparatus than above described may be used. In Gillette and Hill's "Concrete Construction" will be found detail drawings of what are termed "sand ejectors," consisting of a row of conical hoppers now used extensively for washing filter sand. From the bottom of each hopper the sand and water are forced to the top of the next hopper by a stream of water passing through an ejector. The dirty water overflows at the top of each hopper, and finally clean sand is discharged into receiving bins or buckets. One man can readily attend to feeding the sand into the first hopper and another man will handle the discharge. It requires about 3,000 gals. of water per cu. yd. of sand washed, so that with an output of 36 cu. yds. of sand in 10 hrs., the amount of water to be pumped is 108,000 gals. A gasoline pump may be used.

With such an output the cost would be about as follows:

	Per Day.	Per Cu. Yd.
2 laborers at $2	$4.00	$0.111
1 man on pump	3.00	0.083
Fuel, etc., for 5 hp. pump	1.00	0.028
Total	$8.00	$0.222

The cost of pumping can be greatly reduced where a larger yardage is to be washed daily.

For other data on sand washing with ejectors see the part of the section on Waterworks devoted to sand filtering.

Cost of Washing Gravel.—In the Railway Section will be found data on the cost of washing gravel for railway ballast.

Cost of Transporting in Push Carts.—For hauling concrete over comparatively level runways, two-wheel push carts, or concrete buggies, are far more economic than wheelbarrows. A cart having a capacity of 6 cu. ft., and holding about 0.2 cu. yd. of concrete, is pushed by one man. With wages at 15 cts. per hr., and man traveling 200 ft. per min., the cost would be 1¼ cts. per cu. yd. per 100 ft. of distance from mixing board to point of dumping the con-

crete. Two lines of plank should be laid for the wheels to travel on.

Cost of Making Concrete by Hand.—The cost of making concrete by hand may be divided into the following items:

(1) Loading the barrows, buckets, carts or cars used to transport the materials (stone, sand and cement) to the mixing board.

(2) Transporting and dumping the materials.

(3) Mixing the materials by turning with shovels or hoes.

(4) Loading the concrete with shovels into barrows, buckets, carts or cars.

(5) Transporting the concrete to place.

(6) Dumping and spreading.

(7) Ramming.

(8) Forms, runways, cement house, bins, etc.

(9) Finishing the surface of the concrete.

(10) Superintendence and general expenses.

Unloading the Materials From Cars.—The stone and sand will ordinarily be delivered by wagons or cars and dumped into stock piles as near the proposed work as possible, without being in the way after construction begins. The contractor should use forethought not only in planning the location of his stock piles, but also in providing a large enough storage capacity to tide over irregularities in the delivery of materials, especially where materials come by rail from a distance. It is usually a short-sighted policy to attempt to unload direct from the railway cars onto the mixing board, without providing a stock pile; for the foreman will be spending most of his time trying to get the railroad to deliver materials promptly. By all means provide stock piles, unless there is some good reason to the contrary.

Sand can be dumped directly on the ground, but broken stone (unless it is very small, ¾-in. or less in size) should always be dumped upon a plank floor, well made. Such a floor should consist of 2-in. plank laid on 4 x 6-in. stringers, firmly bedded in the ground and spaced about 3 ft. apart. Never lay a lot of loose plank directly upon the ground, without stringers, for they are sure to settle unevenly under the load, and thus make it difficult to shovel up the stone. The object of the plank is to provide an even surface along which a square pointed shovel can be pushed in loading barrows, carts, etc. I find that a man can load 18 or 20 cu. yds. of broken stone into wheelbarrows in 10 hrs., if he is shoveling off a well-laid plank platform, but he will not average more than 12 or 14 cu. yds. a day shoveled from a pile without a plank flooring. The reason is that a shovel can be shoved with difficulty into a mass of broken stone (2-in. size), but can readily be shoved along a plank floor Incidentally I may add that broken stone delivered in hopper-bottom cars can be shoveled with difficulty as compared with shoveling in flat-bottom cars; the ratio being about 14 cu. yds. per man per day from hopper-bottom cars as compared with 20 cu. yds. from flat cars. On the other hand, the hopper-bottom coal car

should always be chosen where it can be dumped through a trestle. If the amount of work to be done will justify the expense a trestle may be built. Often, however, there is a railroad embankment which can be dug away for a short distance and stringers placed to support the track. Then the cars can be dumped into the hole thus made, and the material shoveled out and down the slope.

Many foremen for railway companies waste hundreds of dollars by shoveling the materials from freight cars out upon the earth—often upon the side of an embankment where shoveling is very difficult. In many cases it would have paid well to have unloaded the cars by the aid of a stiff-leg derrick and iron buckets or skips loaded by the shovelers in the cars; these skips being dumped upon a well-made platform. In other cases chutes lined with sheet iron would have served to deliver the stone upon a plank flooring at the foot of the embankment, just as coal is delivered into a cellar. Damp sand will not slide down a chute on a slope of 1½ to 1, but coarse broken stone, if given a start when cast, with the shovel, will slide on an iron-shod slope of 3 or 4 to 1.

If the material is delivered in wagons it seldom is necessary to have large stock piles provided the wagons come direct from the sand pit and the quarry.

Cost of Loading the Materials.—A man who is a willing worker can readily load 20 cu. yds. of sand into a barrow or cart in 10 hrs., but under poor foremen, or when laborers are scarce, it is not safe to count upon more than 15 cu. yds. a day, or, say, 10 cts. per cu. yd. for loading. Practically the same figures hold true of broken stone shoveled off a good plank floor; but, if the stone is shoveled off the ground, estimate 15 cu. yds. a day under good management, or 12 cu. yds. a day under poor management. Since in a cubic yard of concrete there are ordinarily about 1 cu. yd. of broken stone and about 0.4 cu. yd. of sand, the cost of loading the materials into wheelbarrows and carts is as follows, wages being 15 cts. per hour:

1 cu. yd. stone loaded for	11 cts.
0.4 cu. yd. sand loaded for	4 cts.
1 cu. yd. concrete loaded for	15 cts.

The cement can be loaded with more ease than the other materials, whether it is in barrels or in bags, and the cost of loading it into barrows or carts will be not over 2 cts. per cu. yd. of concrete, thus making a total of 17 cts. per cu. yd. for loading the concrete materials into barrows or carts.

Cost of Transporting the Materials.—The most common way of transporting the materials from stock piles to the mixing board is in wheelbarrows over plank runways. A wheelbarrow is usually loaded with 2 sacks of Portland cement (200 lbs.), or with 2 cu. ft. of stone or of sand, if a steep rise must be made to reach the mixing platform; but, if the run is level, 300 lbs. of cement, or 3 cu. ft. of sand or stone is a common wheelbarrow load. A man wheeling a barrow travels at the rate of about 200 ft. per minute, going and coming, and loses ¾ minute each trip dumping the load, fixing run

planks, etc. An active man will do 20 or 25% more work than this, while a very lazy man may do 20% less. With wages at 15 cts. per hour, the cost of wheeling the materials for 1 cu. yd. of concrete may be obtained by the following rule:

To a fixed cost of 4 cts. (for lost time) add 1 ct. for every 20 ft. of distance from stock pile to mixing board if there is a steep rise in the runway, but if the runway is level add 1 ct. for every 30 ft. distance of haul. Since loading the barrows costs 17 cts. per cu. yd. the total fixed cost is 4 + 17 cts. or 21 cts. per cu. yd., to which is added 1 ct. for every 20 or 30 ft. of haul, according to the character of the runway.

I have frequently seen small stock piles located as close as possible to mixing boards, so that wheelbarrows were not used, the materials being carried in shovels direct to the mixing boards. On work of any considerable size this is a very foolish plan, as we can readily see. It takes from 100 to 150 shovelfuls of stone to make 1 cu. yd. It therefore costs at the rate of 50 cts. per cu. yd. to carry it 100 ft. and return empty handed, for in walking short distances the men travel very slowly—about 150 ft. per minute. From this it appears that it costs more to walk even half a dozen paces with stone carried in shovels than to wheel it in barrows. Of course, by using large coal scoops the cost of carrying material in shovels could be reduced to one-half or one-third the cost with ordinary shovels; but scoops are never used in mixing concrete.

Another mistake that is very commonly made by foremen is to provide no plank runways from the stock pile to the mixing board, but instead to run the wheelbarrows over the ground. This is bad enough even in dry weather over a very hard packed earth path, but after a rain or on a soft pathway it means a great loss of efficiency. Had I not seen this error committed repeatedly, I should not mention it, for it would seem that no foreman could be so shortsighted as not to provide a few planks for runways.

Where the runway must rise to the mixing board, give it a slope or grade seldom steeper than 1 in 8, and if possible flatter. Make a runway on a trestle at least 18 ins. wide, so that men will be in no danger of falling. See to it, also that the planks are so well supported that they do not spring down when walked over, for a springy plank makes hard wheeling. If the planks are so long between the "horses" or "bents" used to support them, that they spring badly, it is usually a simple matter to nail a cleat across the underside of the planks and stand an upright strut underneath to support and stiffen the plank.

Materials may be hauled in one-horse dump-carts for all distances more than 50 ft. (from stock pile to mixing board) at a cost less than for wheelbarrow hauling. A cart should be loaded in 4 mins. and dumped in about 1 min., making 5 mins. lost time each round trip. It should travel at a speed of not less than 200 ft. per min., although it is not unusual to see variations of 15 or 20%, one way or another, from this average, depending upon the management of the work. A one-horse cart will readily carry enough stone and

sand to make ½ cu. yd. of concrete, if the roads are fairly hard and level; and a horse can pull this load up a 10% (rise of 1 ft. in 10 ft.) planked roadway provided with cleats to give a foothold. If a horse, cart and driver can be hired for 30 cts. per hour, the cost of hauling the materials for 1 cu. yd. of concrete is given by the following rule:

To a fixed cost of 5 cts. (for lost time at both ends of haul) add 1 ct. for every 100 ft. of distance from stock pile to mixing board. Where carts are used it is possible to locate the stock piles several hundred feet from the mixing boards without adding materially to the cost of the concrete. It is well, however, to have the stock piles in sight of the foreman at the mixing board, so as to insure promptness of delivery.

Cost of Mixing the Materials.—This element of cost depends upon the number of times that the materials are turned over with shovels. I have seen street paving work where the inspection was so lax that the contractor was required to turn over the mass of sand, cement and stone only three times before shoveling it into place. On the other hand, the contractor is rarely required to turn over the cement and sand more than three times dry and three times wet to make the mortar, and then turn over the mortar and stone three times. A willing workman, under a good foreman, will turn over mortar at the rate of 30 cu. yds. in 10 hrs., lifting each shovelful and casting it into a pile. This means a cost of 5 cts. per cu. yd. of mortar for each turn; but as there is seldom more than 0.4 cu. yd. of mortar per cu. yd. of concrete, we have a cost of 2 cts. per cu. yd. of concrete for each turn that is given to the mortar. So if the mortar is given 6 turns before adding the stone, we have 2 cts. × 6 which is 12 cts. per cu. yd. of concrete for mixing the mortar. Then if the mortar and stone are turned three times we have 5 cts. × 3, or 15 cts. more for mixing, thus making a total of 27 cts. per cu. yd. for mixing the concrete, wages being 15 cts. per hr.

I recall seeing one specification that called for 6 turns of the mortar dry and 3 turns wet. Under such a specification the cost of mixing the mortar would be 50% more than I have assumed in the example just given. Specifications for hand mixing should always state the number of turns that will be required, but frequently they do not, thus leaving the contractor to guess at the probable requirements of the inspector. In such a case it is a good plan to use hoes instead of shovels for mixing the mortar, because in this way a good mortar can be mixed with much greater rapidity than when an inspector insists on 6 to 9 turns with shovels, as frequently happens when specifications are ambiguous.

As above stated, it often happens that on city pavement work, two turns of the mortar, followed by two turns of the mortar and stone, are considered sufficient. In such a case the cost of mixing the mortar is 2 cts. × 2, or 4 cts. per cu. yd. of concrete; to which is added 5 cts. × 2, or 10 cts., for mixing the mortar and stone, making in all 14 cts. per cu. yd. of concrete. When concrete is mixed very wet, or sloppy, this amount of mixing appears to give good results.

Where a given number of turns of concrete is specified, disputes often occur between inspectors and foremen as to whether shoveling into wheelbarrows constitutes a "turn" or not, and whether any subsequent shoveling in getting the concrete to its final resting place constitutes a "turn." It seems but fair to count each handling with the shovel as a turn, no matter when or where it occurs, but inspectors will not always look upon it in that light.

The foregoing costs of mixing apply to work done by diligent men; but easy-going men will make the cost 25 to 50% greater. I have seen this latter class of men most frequently on day labor work for cities, railways and other companies and corporations whose foremen have little or no incentive to secure a fair day's work from the men.

Cost of Loading and Hauling Concrete.—The cost of loading concrete, after it is mixed, is less than the cost of loading the materials separately before mixing, because while the weight is greater (due to the added water), the bulk or volume of the concrete is much less than the volume of the ingredients before mixing. Moreover a smooth mixing board, and the presence of the foreman, secures more rapid work. In shoveling any material a large part of the work consists in forcing the shovel into, or under, the mass to be lifted. With wages at 15 cts. per hour, the cost of loading concrete into barrows or buckets should not exceed 12 cts. per cu. yd. The cost of wheeling it after loading is practically the same as for wheeling the dry ingredients, as given by the rule on page 272. The cost per cubic yard of loading and wheeling is therefore given by this rule: To a fixed cost of 16 cts. (for loading and lost time) add 1 ct. for every 30 ft. of level haul.

If the concrete must be elevated, a gallows frame, or a mast with a pulley block at the top, a team of horses and a rope for hoisting the skip load of concrete, can often be used to advantage.

Another method, well worthy of more frequent use, consists in wheeling the barrows of concrete to a gallows frame where they are raised by a horse, and when wheeled to place.

In building railway abutments, culverts, and the like, it is often desirable to locate the mixing board on high ground, perhaps at some little distance from the forms. If this can be done, the use of derricks may be avoided as above suggested or by building a light pole trestle from the mixing board to the forms. The concrete can then be wheeled in barrows and dumped into the forms. If the mixing board can be located on ground as high as the top of the concrete structure is to be, obviously a trestle will enable the men to wheel on a level runway. Such a trestle can be built very cheaply, especially where second-hand lumber, or lumber that can be used subsequently for forms is available. A pole trestle whose bents are made entirely of round sticks cut from the forest is a very cheap structure, if a foreman knows how to throw it together and up-end the bents after they are made. I have put up such trestles for 25 cts. per lin. ft. of trestle, including all labor of cutting the round timber, erecting it, and placing a plank flooring 4 ft. wide on top. The stringers and

flooring plank were used later for forms, and their cost is not included. A trestle 100 ft. long can thus be built at less cost than hauling, erecting and taking down a derrick; and once the trestle is up it saves the cost of operating a derrick.

Concrete made with Portland cement (but not with natural cement) can be hauled long distances in a cart or wagon before it begins to harden. This fact should be taken advantage of by contractors far oftener than it is. I am inclined to think that the extensive use of natural cement, which sets too quickly to admit of hauling far, has blinded contractors to the possibilities of saving money by hauling Portland cement concrete long distances. Since a cart is readily hauled at a speed of 200 ft. a minute, where there are no long steep hills, it is evident that in 6½ minutes a cart can travel a quarter of a mile; in 13 minutes, half a mile; and in 26 minutes, a mile. Portland cement does not begin to set for 30 minutes; hence it may be hauled a mile after mixing it. The cost of hauling concrete with one-horse dump-carts is practically the same as the cost of hauling its dry ingredients.

Cost of Dumping, Spreading and Ramming.—The cost of dumping wheelbarrows and carts is included in the rules of cost already given, excepting that in some cases it is necessary to add the wages of a man at the dump who assists the cart drivers or the barrow men. Thus in dumping concrete from barrows into a deep trench or pit, it is usually advisable to dump into a galvanized iron hopper provided with an iron pipe chute. One man can readily dump all the barrows that can be filled from a concrete mixer in a day, say 150 cu. yds. At this rate of output the cost of dumping would be only 1 ct. per cu. yd., but if one man were required to dump the output of a small gang of men, say 25 cu. yds., the cost of dumping would be 6 cts. per cu. yd.

Concrete dumped through a chute requires very little work to spread it in 6-in. layers; and, in fact, concrete that can be dumped from wheelbarrows, which do not all dump in one place, can be spread very cheaply; for not more than half the pile dumped from the barrow needs to be moved, and then moved merely by pushing with a shovel. Since the spreader also rams the concrete, it is difficult to separate these two items. As nearly as I have been able to estimate this item of spreading "dry" concrete dumped from wheelbarrows in street paving work, the cost is 5 cts. per cu. yd. If, on the other hand, nearly all the concrete must be handled by the spreaders, as in spreading concrete dumped from carts, the cost is fully double, or 10 cts. per cu. yd. And if the spreader has to walk even 3 or 4 paces to place the concrete after shoveling it up, the cost of spreading will be 15 cts. per cu. yd. For this reason it is apparent that carts are not as economical as wheelbarrows for hauling concrete up to about 200 ft., due to the added cost of spreading material delivered by carts.

The preceding discussion of spreading is based upon the assumption that the concrete is not so wet that it will run. Obviously

where concrete is made of small stones and contains an excess of water, it will run so readily as to require little or no spreading.

The cost of ramming concrete depends almost entirely upon its dryness and upon the number of cubic yards delivered to the rammers. Concrete that is mixed with very little water requires long and hard ramming to flush the water to the surface. The yardage delivered to the rammers is another factor, because if only a few men are engaged in mixing they will not be able to deliver enough concrete to keep the rammers properly busy, yet the rammers by slow though continuous pounding may be keeping up an appearance of working. Then, again, I have noticed that the slower the concrete is delivered the more particular the average inspector becomes. Concrete made "sloppy" requires no ramming at all, and very little spading.

I have had men do very thorough ramming of moderately dry concrete for 15 cts. per cu. yd., where the rammers had no spreading to do, the material being delivered in shovels. It is rare indeed that spreading and ramming can be made to cost more than 40 cts. per cu. yd., under the most foolish inspection, yet one instance is recorded below of even higher cost.

If engineers specify a dry concrete and "thorough ramming" they would do well also to specify what the word "thorough" is to mean, using language that can be expressed in cents per cubic yard. It is a common thing, for example, to see a sewer trench specification in which one tamper is required for each two men shoveling the backfill into the trench; and some such specific requirement should be made in a concrete specification if close estimates from reliable contractors are desired. Surely no engineer will claim that this is too unimportant a matter for consideration when it is known that ramming can easily be made to cost as high as 40 cts. per cu. yd., depending largely upon the whim of the inspector.

Example of High Cost of Tamping.—Mr. Herman Conrow is authority for the following data: 1 foreman, 9 men mixing, 1 ramming, averaged 15 cu. yds. a day, or only 1½ cu. yds. per man per day, when laying wet concrete. When laying dry concrete the same gang averaged only 8 cu. yds. a day, there being 4 men ramming. With foreman at $2 and laborers at $1.50 a day, the cost was $2.12 per cu. yd. for labor on the dry concrete as against $1.13 per cu. yd. for the wet concrete. Three turnings of the stone with a wet mortar effected a better mixture than four turnings with a dry mortar. The ramming of the wet concrete cost 10 cts. per cu. yd., whereas the ramming of the dry concrete cost 75 cts. per cu. yd. I think this is the highest cost on record for ramming. It is evident, however, that the men were under a poor foreman, for an output of only 15 cu. yds. per day with 10 men is very low for ordinary conditions. Moreover, the high cost of ramming indicates either poor management or the most foolish inspection requirements.

Cost of Rolling and Finishing Concrete Floors.—I am indebted to Mr. Ernest L. Ransome for the following:

When concrete floors are built directly on the ground, there is no necessity of having a concrete as rich in cement as when the floor spans an opening. A mixture of 1 part Portland cement, 4 parts sand and 8 parts gravel or broken stone is strong enough, and this requires less than three-quarters of a barrel of cement per cubic yard. If hand mixing is used, more cement is needed, but we are assuming that the materials are thoroughly mixed. Actual tests have demonstrated that more cement is required with hand mixing than with machine mixing.

The concrete should be spread in a layer 3 to 5 ins. thick, depending upon the nature of the subsoil and the loads the floor will have to support. Then the concrete should be rolled, for rolling is more effective than tamping and costs far less. The first attempts at rolling were unsuccessful because a roller of too great weight was used. Mr. Ransome discovered that *a light roller should be used for the first rolling, followed by rolling with a heavier roller, and finishing with a roller still heavier.*

The Ransome Concrete Machy. Co., of Dunellen, N. J., makes rollers of three sizes to be used successively, weighing: No. 1, 290 lbs.; No. 2, 375 lbs.; No. 3, 645 lbs.

One laborer will readily roll 7,500 sq. ft. in a 9-hr. day. If the floor is 4 ins. thick, this is equivalent to nearly 100 cu. yds. With wages at $1.50 a day, the cost is 0.2 ct. per sq. ft., or 1½ cts. per cu. yd. for the rolling.

An interesting fact about rolling concrete is this: The water is flushed to the surface and may even run off in a thin stream, but the water is perfectly clear, carrying no cement in suspension. Whereas, when concrete is tamped, the water is milky, due to the cement that is flushed to the surface.

After the concrete is rolled, a finishing coat of mortar is applied.

Most contractors have finished floors with a coating of cement mortar immediately following the laying of the body of the floor. There are several objections to this practice. In the first place, should a heavy rain fall before the floor is roofed over, the surface will be damaged. This objection, however, is not so serious as another. Scaffolding placed on green concrete mars its surface, and, in addition to this, drippings of mortar and concrete from above spoil the surface. Moreover, it is very difficult to put a finishing coat on reinforced concrete floors when they are still soft. To escape these objections Mr. Ransome invented "Ransomite," which is a liquid that causes new concrete to adhere to old. The body of a concrete floor is built, as above described, and the finishing coat is not put on until the scaffolding and forms are removed from above. Then the floor is given a wash of "Ransomite," at a cost of approximately ¼ ct. per sq. ft. for material and labor. Upon the floor is spread a layer of cement mortar ½ to 1 in. thick, the mortar being 1 part Portland cement to 2 parts sand.

A skilled finisher at $4 a day, with a helper at $2.50, will finish 500 sq. ft. of floor in a day. Considerably more than 1,000 sq. ft.

a day have been finished by a skillful and willing man, but, assuming only 500 sq. ft. a day, the cost of finishing is about 1¼ cts. per sq. ft.

For further data on finishing floors, see the part of the section on Roads and Pavements where costs of cement walks are given.

Cost of Superintendence.—This item is obviously dependent upon the yardage of concrete handled under one foreman and the daily wages of the foreman. If a foreman receives $3 a day and is bossing a job where only 12 cu. yds. are placed daily, we have a cost of 25 cts. per cu. yd. for superintendence. If the same foreman is handling a gang of 20 men whose output is 50 cu. yds., the superintendence item is only 6 cts. per cu. yd. If the same foreman is handling a concrete-mixing plant having a daily output of 150 cu. yds., the cost of superintendence is but 2 cts. per cu. yd. I have given these elementary examples simply because figures are more impressive than generalities, and because it is so common a sight to see money wasted by running too small a gang of men under one foreman.

Of all classes of contract work, none is more readily estimated day by day than concrete work, not only because it is usually built in regular shapes whose volumes are easily ascertained at the end of each day, but because a record of the bags, or barrels, or batches gives a ready method of computing the output of each gang. For this reason small gangs of concrete workers need no foreman at all, provided one of the workers is given command and required to keep tally of the batches. If the efficiency of a gang of 6 men were to fall off, say, 15%, by virtue of having no regular non-working foreman in charge, the loss would be only $1.35 a day—a loss that would be more than counterbalanced by the saving of a foreman's wages. Indeed, the efficiency of a gang of men would have to fall off 25%, or more, before it would pay to put a foreman in charge. I know by experience that in many cases the efficiency will not fall off at all, provided the gang knows that its daily progress is being recorded, and that prompt discharge will follow laziness. Indeed, I have more than once had the efficiency increased by leaving a small gang to themselves in command of one of the workers who was required to punch a hole in a card for every batch.

To reduce the cost of superintendence there is no surer method than to work two gangs of 18 to 20 men, side by side, each gang under a separate foreman who is striving to make a better showing than his competitor. This is done with marked advantage in street paving, and could be done elsewhere oftener than it is.

In addition to the cost of a foreman in direct charge of the laborers, there is always a percentage of the cost of general superintendence and office expenses to be added. In some cases a general superintendent is put in charge of one or two foremen; and, if he is a high-salaried man, the cost of superintendence becomes a very appreciable item.

Summary of Costs of Making Concrete by Hand.—Having thus

analyzed the costs of making and placing concrete, we can understand why it is that printed records of costs vary so greatly. Moreover, we are enabled to estimate the labor cost with far more accuracy than we can guess it; for by studying the requirements of the specifications, and the local conditions governing the placing of stock piles, mixing boards, etc., we can estimate each item with considerable accuracy. My purpose, however, has not been solely to show how to predict the labor cost, but also to indicate to contractors and their foremen some of the many possibilities of reducing the cost of work once the contract has been secured. I have found that an analysis of costs, such as above given, is the most effective way of discovering unnecessary "leaks," and of opening one's eyes to the possibilities of effecting economies in any given case.

To indicate the method of summarizing the costs of making concrete by hand, let us assume that the concrete is to be put into a deep foundation requiring wheeling a distance of 30 ft.; that the stock piles are on plank 60 ft. distant from the mixing board; that the specifications call for 6 turns of gravel concrete thoroughly rammed in 6-in. layers; and that a good sized gang of, say, 16 men (at $1.50 a day each) is to work under a foreman receiving $2.70 a day. We then have the following summary by applying the rules already given:

	Per cu. yd. concrete.
Loading sand, stone and cement	$ .17
Wheeling 60 ft. in barrows (4 + 2 cts.)	.06
Mixing concrete, 6 turns at 5 cts.	.30
Loading concrete into barrows	.12
Wheeling 30 ft. (4 + 1 ct.)	.05
Dumping barrows (1 man helping barrowman)	.05
Spreading and heavy ramming	.15
Total cost of labor	$ .90
Foreman at $2.70 a day	.10
Grand total	$1.00

To estimate the daily output of this gang of 16 laborers proceed thus: Divide the daily wages of all the 16 men, expressed in cents, by the labor cost of the concrete in cents, the quotient will be the cubic yards output of the gang. Thus, 2,400 ÷ 90 is 27 cu. yds. in this case.

In street paving work where no man is needed to help dump the wheelbarrows, and where it is usually possible to shovel concrete direct from the mixing board into place, and where half as much ramming as above assumed is usually satisfactory, we see that the last four labor items instead of amounting to 12 + 5 + 5 + 15, or 37 cts., amount only to one-half of the last item, ½ of 15 cts., or 7½ cts. This makes the total labor cost only 60 cts. instead of 90 cts. If we divide 2,400 cts. (the total day's wages of 16 men) by 60 cts. (the labor cost per cu. yd.), we have 40 which is the cubic yards output of the 16 men. This greater output of the 16 men reduces the cost of superintendence to 7 cts. per cu. yd.

Cost of Mixing Concrete With Machine.—Care must be taken not to confuse the cost of mixing concrete with the cost of delivering materials to the mixer and conveying the concrete away from the mixer. A study of the various costs given on subsequent pages will show that the cost of mixing alone is only a small part of the total cost of making concrete.

If all the materials are delivered to the machine in wheelbarrows, and if the concrete is conveyed away in wheelbarrows, the cost of making concrete, even with machine mixers, is high. On the other hand, where the materials are fed from bins by gravity into the mixer, and where the concrete is hauled away in cars, the cost of making the concrete may be very low.

There are three types of mixers: (1) Batch mixers; (2) continuous mixers; (3) gravity mixers. Cube mixers, double-cone mixers, and drum mixers are batch mixers in which a charge is rotated for 10 or 15 turns and then discharged all at once. The continuous mixers have paddles or plows that stir up the materials as fast as they are delivered, a continuous stream of concrete being discharged. In one type of gravity mixer the falling materials strike baffle plates which perform the mixing. In the more common type (the Hains), the materials pass through three funnel-shaped hoppers, the hour glass action causing the mixing.

Batch mixers are commonly made in three sizes, ½-yd., ¾-yd. and 1-yd. It is generally considered sufficient to give the mixer 10 or 15 turns, occupying 1 to 1½ mins., after charging it with a batch; but as some time is consumed in charging and discharging, etc., it is safe to count on only one batch every 3 mins., or 200 batches in 10 hrs. If each batch is ½-yd., the daily output is 100 cu. yds.; if the batch is 1 yd., the daily output is 200 cu. yds.

Where the work is well organized, and no delays occur in delivering the materials to the mixer, a batch every 2 mins., or 300 batches in 10 hrs., will be averaged; and there are a few records of 1 batch every 1½ mins., and even less.

Not more than 12 hp. are required to run a ¾-yd. mixer. Where materials are delivered from bins or skips, 2 men will charge a ¾-yd. mixer and 1 man will attend to dumping it, and a gasoline engine consuming 10 gals. of gasoline per 10-hr. day at 12½ cts. per gal., will represent the full cost of labor and fuel for mixing 200 cu. yds. If the 2 men are paid $1.50 each, and 1 man at $1.75, the cost of labor and fuel is only $6.00, or 3 cts. per cu. yd. It is not in the *mixing*, therefore, that the money is consumed, but in conveying materials to and from the mixer, in ramming the concrete, in installing the plant for mixing and conveying, and in interest and depreciation charges.

For tables of sizes, weights, capacities, etc., of mixers made by 11 different manufacturers, see Gillette and Hill's "Concrete Construction," p. 660, etc.

A batch mixer will, in general, require the following engine power:

	HP.
¼ cu. yd. batch mixer	7
½ cu. yd. batch mixer	10
⅔ cu. yd. batch mixer	14
1 cu. yd. batch mixer	20

It is wise to provide a boiler power about 50% in excess of the engine power.

The weights of batch mixers, with and without engine and boiler, seldom exceed the following:

Size of batch, cu. yd.	¼	½	⅔	1
Weight of mixer on skids, lbs.	3,500	3,800	6,000	6,700
Ditto with engine and boiler, lbs.	7,000	7,500	12,000	13,500

Prices vary considerably, but, for purposes of estimating, assume about 10 cts. per lb.

The above sizes of "batches" are based not upon the loose measure of the materials, but of the concrete rammed in place.

Cost of Mixing With a Gravity Mixer.—Mr. G. B. Ashcroft states that a small gravity mixer of the Hains type was used in the building of a dock for The William Skinner Ship-Building & Dry Dock Co., of Baltimore, Md. It consisted of two conical hoppers, one above the other, and above these were four small pyramidal hoppers for measuring the sand and stone, and above these were small bins. One man at each conical hopper tending the gates, and two men at the pyramidal hoppers (4 men in all) constituted the gang on the mixer. A scow load of sand and another of broken stone were hauled alongside the bulkhead on which the mixer stood, and a clamshell bucket dredge was used to load the sand and stone from the scows into the bins of the mixer. Each batch was 25 cu. ft. of 1:2:5 concrete rammed into place. The record for 10 hrs. was 110 batches, making about 35 cts. per cu. yd. as the labor cost. Wages of common laborers were $1.50. The concrete was run directly into place through chutes; and the mixer was moved from place to place by means of the dredge boom.

On the Cedar Grove Reservoir, built for Newark, N. J., a large gravity mixer of the Hains type was used. The best day's output was 403 cu. yds.; the average output during the best month was 302 cu. yds.; and the average of the whole job was 225 cu. yds. per 10-hr. day. The stone, sand and cement were all raised by bucket elevators to the top of the high wooden tower that supported the bins and the mixer. There were 10 men operating the mixer, so that (exclusive of power, interest and depreciation) the labor cost of mixing averaged only 7 cts. per cu. yd.; and during one month it was as low as 5 cts. per cu. yd. This does not include delivering the materials to the men at the mixer, nor does it include conveying the concrete away and placing it. The work was done by contract.

On the Pittsburg filter construction in 1906, a Hains mixer was used, and its output was 500 cu. yds. per 10-hr. day.

Cost of Forms.—It is a common practice to record the cost of forms or molds in cents per cubic yard of concrete, giving separately the cost of lumber and labor. This should be done, but the analysis of the cost of forms should always be carried a step farther. The

records should be so kept as to show the first cost per M (i. e., 1,000 ft. B. M.) of lumber, the number of times the lumber is used, the labor cost of erecting, and the labor cost of taking down the forms each time—all expressed in M ft. B. M. Thus only is it possible to compare the cost of forms on different kinds of concrete work, and thus only can accurate predictions be made of the cost of forms for concrete work having dimensions differing from work previously done. It is well also to make record of the number of square feet of exposed concrete surface to which the forms were applied. There are three ways, therefore, of recording the cost of forms: (1) In cents per cubic yard of concrete; (2) in cents per square foot of concrete face to which forms are applied; and (3) in dollars per M ft. B. M. of lumber used—in all three cases keeping the cost of materials and labor separate. Furthermore, it is well to make a sketch of the construction of the forms, and attach the sketch to the record of cost.

In estimating the probable cost of forms I find the following method most reliable: First, after ascertaining the time limit within which the work must be completed, determine the number of cubic yards of concrete that must be laid each day, after allowing liberally for delays. Knowing the number of cubic yards, estimate the number of thousand feet board measure of forms required to encase the concrete to be placed in a day. This will give the *minimum* amount of lumber required, for it is never permissible to move the forms until the concrete has hardened over night, except when concrete is in a small arch, as in a sewer. This brings us to a very important question in economics. Thousands of words have been written on the advantages and disadvantages of using "wet" or "dry" concrete, but I have never seen mention of one of the most forceful objections to the use of concrete mixed so wet that it is sloppy. I refer to the slowness with which such concrete hardens. Obviously, the more slowly it hardens, the longer must the forms be left in place; and the longer the forms are left in place the more lumber will be required; the more the lumber, the greater the cost of forms per cubic yard of concrete.

A concrete mixed "dry," and rammed, will harden over night, so that in retaining wall construction it is safe to remove the forms the next morning; but, where the concrete has been mixed "sloppy," I have seen whole sections of wall fall out upon the removal of forms twelve hours after placing the concrete. In cold weather the setting is further delayed, and in very cold weather it may cease entirely unless proper precautions are taken. Specifications relating to sloppy concrete usually provide that wall forms shall not be moved within 48 hrs. after placing the concrete; but in hot weather it is often safe to remove the forms in 24 hrs. or less.

Forms for concrete arches or beams must obviously be left in place longer than in wall work, because of the tendency to fall by rupture across the arch or beam. Forms for small circular arches, like sewers, may be removed in 18 to 24 hrs. if dry concrete is used; but in 24 to 48 hrs. if wet concrete is used. Forms for large arch

culverts and arch bridges are seldom taken down in less than 14 days, and it is often specified that they must not be struck for 28 days after placing the last of the concrete. This last requirement is probably necessary where the backfilling over the arch is put on at once; but, except in the case of arches of great span, there appears to be no sufficient reason for keeping the centers so long under the arch, provided they can be used elsewhere. Indeed, I am inclined to think that a week's time is ample for arches having a span of 40 ft. or less, provided no filling is placed on the arch. In fact, a study of the compressive strength tests given in Falk's "Cements, Mortars and Concretes," pages 128, 131, etc., shows that the difference of compressive strength between 7-day and 28-day Portland cement mortar and concrete is often less than 25%, and averages about 50%; and that in any case concrete a week old is amply strong enough to hold its own weight in an arch of moderate size. Progressive settlement of the abutments might in some cases be given as a reason for leaving centers a long time in place, but abutments founded on rock or on piles do not show progressive settlement after the striking of centers, unless the subsequent jarring of trains causes the piles to go down.

Forms supporting concrete-steel floors and beams are usually left in a place at least a week.

The consideration of the time element in the use of forms is essential in making an accurate forecast of the quantity of lumber that will be required in any given case. A few additional suggestions will not, therefore, be out of place.

Often the uprights of studs used to hold the sheeting plank are also used as legs for a trestle to support a track or runway over which the concrete is transported. In such a case the amount of timber in the forms is considerably more than would be indicated by considering merely the length of time that the forms must stand before removal; for, so long as the uprights stand, it is impossible to remove the sheeting plank where ordinary kinds of forms are used. I have seen many instances of unnecessary expenditure of money for forms due to neglect to consider this fact. Bear in mind, therefore, that it may be cheaper to provide a movable derrick, or to use a cableway for delivering the concrete, rather than to use the uprights of the forms as posts for a trestle.

I have found it cheaper, as a rule, to build the coping of retaining walls after finishing the wall itself. One of the reasons for this is that a projecting coping is apt to fall, due to its own weight, if the forms are not left in place longer than it is necessary to leave the forms for the wall below the coping.

This leads us to the subject of building forms in panels that can be shifted from place to place without tearing the forms to pieces and building them up again. When panels can be used, it is evident that the cost of labor and lumber for forms may be reduced to a few cents per cubic yard of concrete. Examples of low cost of sewer work where the forms are thus shifted in sections will be found on

subsequent pages. Even high retaining walls may thus be built with movable forms.

There are few classes of concrete work where, at the expense of a little thought in designing movable forms, a great expense in lumber may not be saved.

Having estimated the quantity of lumber required for any given concrete job, and the number of times that it can be used, the labor cost of framing, erecting and taking down the forms may be calculated thus: With carpenters' wages at 25 cts. per hour, and laborers' wages at 15 cts. per hour, working 1 laborer to 2 carpenters, my records show that ordinary forms for walls, arches, etc., can be framed and erected for $6 per M ft. B. M., when men are working for a contractor. The forms can be carefully torn apart, taken down and moved a short distance, for $1.50 per M; making the total labor cost $7.50 per M for each time that the forms are built up and torn down. Where the forms are built in panels and are not ripped apart and nailed together again at every move, there is only the cost of moving them each time after they have once been built, and this may not exceed 50 cts. per M for each move. Moreover forms used in panels last much longer since the lumber is not injured by being repeatedly torn apart.

Retaining walls, bridge piers and abutments, etc., are commonly provided with forms consisting of 2-in. plank laid in horizontal courses against upright studs. The studs may be of 4 x 6-in. stuff spaced 2½ ft. centers, or 3 x 6-in. spaced 2 ft. centers. In either case the lumber in the studs is about 40% as much as the lumber in the 2-in. sheeting plank. Hence there are 2 ft. B. M. of plank and 0.8 ft. B. M. of studs, or a total of 2.8 ft. B. M. for each square foot of surface area of concrete. If telegraph wire is used to hold the studs from spreading (No. 9 wire weighing 0.06 lb. per ft.), no other lumber is required; but in some designs of forms there are inclined braces against the stud, frequently containing more lumber than the studs themselves. Ordinarily the same forms are used several times, so that the 2.8 ft. B. M. per sq. ft. does not then mean per sq. ft. of concrete, but of forms, and must be divided by the number of times it is used to estimate the lumber per sq. ft. of concrete surface. Thus, if the forms are used 4 times, we have $2.8 \div 4 = 0.7$ ft. B. M. per sq. ft. of concrete surface.

If lumber costs $25 per M, the cost of 2.8 ft. B. M. is 7 cts. It can usually be framed and erected for $8 per M, or 2¼ cts. per sq. ft. of forms containing 2.8 ft. B. M. Hence if the lumber is used 4 times, we have $7 \div 4 = 1\frac{3}{4}$ cts., cost of lumber per sq. ft. of concrete, plus 2¼ cts. per sq. ft. for labor if each time it is taken down and erected costs $8 per M, or a total of 4 cts. per sq. ft. of concrete surface, or 36 cts. per sq. yd. Hence if the wall is 3 ft. thick and requires forms on two faces (front and rear) it will cost 2×36 cts. $= 72$ cts. for forms per cu. yd. of concrete. If it is 6 ft. thick, it will cost 36 cts. per cu. yd. of concrete. If the same sizes of lumber were used for a wall only 1 ft. thick, the cost would be $0.36 ×

3 = $1.08 per cu. yd. Based upon the above assumptions as to amount and cost of lumber, number of times used (4), etc., we have the following rule:

To ascertain the cost of forms per cubic yard of wall, divide $2.16 by the thickness of the wall in feet.

This rule can be expressed in a more general form as follows:

To ascertain the cost of forms per cubic yard of wall, divide $3.80 by the product of the thickness of wall in feet and the number of times the forms are used, to estimate the cost of lumber, and to this add the cost of labor determined by dividing $1.20 by the thickness of the wall in feet.

In the case of a 3-ft. wall where forms are used 4 times, this rule would give us:

$3.80 ÷ (3 × 4) = $0.32 for lumber, to which add $1.20 ÷ 3 = $0.40 for labor, making a total of $0.72 per cu. yd.

For any other price and amount of lumber for forms, a similar rule can readily be made. Such a rule shows very clearly the reason why thin concrete walls where form lumber is used only once or twice cost so much per cubic yard. Thus, if a wall were only 1 ft. thick and lumber were used but once, the above rule would give us a cost of $5 per cu. yd. for forms alone.

For further data on the cost of forms see particularly the sections on Buildings, Bridges, and Sewers. Consult the index under "Concrete, Forms."

Cost of Fortification Work at Fort Point, Cal.—Mr. George H. Mendell gives the following data: The work was the construction of fortifications at Fort Point, near San Francisco. The following experiments were made:

	Experiment No. 1 cu. ft.	Experiment No 2 cu. ft.	Experiment No. 3 cu. ft.
1 bbl. Portland cement measured loose	4.42	4.58	4.5*
Water added	2.00	1.75	1.92
Volume of stiff paste resulting	4.00	3.80	3.82
Moist sand added	10.12	11.40	13.50
Water added	2.00	2.50	2.00
Volume of mortar resulting	10.12†	12.30	14.00
Gravel added‡	36.50	36.90	.....
Volume of loose concrete	45.25	43.23	.....
Volume of concrete tamped in place	37.50	.....	.....

*This barrel measured 3½ cu. ft. packed.

†There is some doubt as to the accuracy of this measurement, for it was recorded as 9.12 cu. ft. although it was probably 10.12.

‡This gravel in experiment No. 1, was in ¾-in. sizes down to birdshot; in experiment No. 2 it was the size of beans and smaller. There was a considerable percentage of what should be called sand in the gravel, probably 20%.

In making the concrete all materials were measured loose and a barrel of cement was assumed to measure 4½ cu. ft. The proportions of a batch were 1 : 3 : 8; the 8 being 8 × 4½, or 36 cu. ft. of stone and gravel. In making a mass of concrete 60 ft. long, 40 ft.

wide and 30 ft. high, a careful record was kept of the cost of several weeks' work, measuring 1,825 cu. yds. in place:

	Cost, per cu. yd.
0.73 bbl. cement at $2.50	$1.82
0.83 cu. yd. stone	1.40
0.26 cu. yd. gravel	.35
0.31 cu. yd. sand	.29
Water	.04
Crushing stone,* mixing and placing concrete	.80
Total	$4.70

*While it is not definitely stated I infer from what is said that the labor of crushing was about 15 cts.

Wages were $2 per day of 8 hrs. for laborers, and $4 for foremen. The cost of timbering and incidental expenses is not included, other than the pay of the men and the foreman. The total volume of all the loose materials, exclusive of the water, was 2,767 cu. yds. before mixing; after mixing, and measured in cars holding 20 cu. ft. each, the volume was 2,433 cu. ft.; after being rammed in place the volume was 1,825 cu. yds. The shrinkage of the concrete under the ramming was therefore 25%. A number of experiments were made on single carloads which showed that a carload of 20 cu. ft. of loose concrete made 15 to 15½ cu. ft. compacted in place.

The stone was quarried at Angel Island, and delivered on the wharf in sizes suitable for a Gates crusher, hauled in wagons to the crusher, which delivered it to the mixer, into which all the ingredients were fed from hoppers automatically. The mixer was of the cylindrical continuous type, and there was difficulty in delivering the materials to it automatically and in the desired proportions. The concrete was delivered by the mixer into cars holding 20 cu. ft. When a car was filled, the door of the mixer was closed for a minute, during which minute another car was put in place, the concrete in the meantime accumulating in the mixer. The cars were pushed by men to the place of deposit, a variable distance of 300 to 600 ft., and discharged through a trestle having an extreme height of 30 ft., gradually diminishing to 4 ft. The concrete was then shoveled into wheelbarrows and wheeled 20 to 40 ft.

During the month of August, 1892, concrete was mixed by hand by a gang of 20 men under 1 foreman. The average 8-hr. output was 45 cu. yds. of concrete at a cost of $1 per cu. yd. for mixing and placing, wages being $2 a day. A batch consisted of 4 bbls. of cement and 144 cu. ft. of gravel and stone, giving 144 cu. ft. of concrete. The materials were piled conveniently around the mixing platform. The stone and gravel were delivered in barrows and spread to an even thickness on the platform. Upon this the sand was wheeled and spread with a straight edge. The cement, also leveled, formed the top layer. Water was added in the turning. The materials were turned twice with shovels, being well dispersed in turning. A third turning resulted from shoveling the concrete into wheelbarrows, and a fourth turning in distributing the concrete.

There was no ascent and the distances were short in wheeling the concrete, and the men were a picked lot.

Cost of Fortification Work.—Mr. L. R. Grabill is authority for the following cost data: The work was upon fortifications built in 1839 for the U. S. Government, and was done by contract, working 8 hrs. per day. The following is the average for 9,000 cu. yds.:

	Per day.	Per cu. yd.
6 laborers wheeling materials to board	$ 7.50	$0.16
8 laborers mixing	10.00	.21
8 laborers wheeling away	10.00	.21
6 laborers placing and ramming	7.50	.16
1 pumpman	1.25	.02
1 water boy	1.00	.02
1 foreman	2.00	.04
Total, 48 cu. yds. a day	$39.25	$0.82

Each batch contained ¾ cu. yd. of 1 : 2·2 : 3 concrete, and was turned four times.

The cost of mixing 4,000 cu. yds. in a machine mixer by day labor (not by contract) was as follows:

	Per day.	Per cu. yd.
32 laborers	$40.00	$0.34
1 pumpman	1.25	.01
1 teamster and horse	2.00	.02
2 water boys	2.00	.02
1 engineman	1.70	.02
1 derrick tender	1.50	.01
1 fireman	1.50	.01
1 foreman	2.88	.03
Fuel (cement barrels largely)	1.25	.01
Total, 118 cu. yds. per day	$54.08	$0.47

The average 8-hr. day's work was 168 batches of 0.7 cu. yd. each. The best day's work was 200 batches. Seven revolutions of the 4-ft. cubical mixer were sufficient. A 12-hp. engine operated the mixer and served also to hoist the material cars up the incline to the mixer. These cars were loaded through trap doors in a bin containing the materials, then the cement was placed upon the load. The material cars moved up one incline, dumped, and passed down another incline on the opposite side. The concrete was dumped into an iron bucket resting on a car, hauled to one of the two boom derricks. These derricks had 80-ft. booms and were swung by bull-wheels. This plant cost about $5,000. The concrete was rammed in 6-in. layers in all cases; and it was found advisable to have one rammer to every 20 batches deposited per day, in addition to the spreaders.

Cost of Concrete Breakwater, Buffalo, N. Y.—Mr. Emile Low gives the following data on the cost of making concrete by contract for the Buffalo Breakwater, in 1902: A 5-ft. cubical mixer was mounted on a scow and run by a 9 x 12-in. horizontal engine. The concrete was 1 : 2 : 1 : 4 cement, sand, gravel and stone. The voids in the sand and gravel were 27%, in the unscreened limestone, 39%. A bag of cement was assumed to be 0.9 cu. ft. The materials were

stored in canal boats alongside. The sand was loaded by 3 shovelers into wheelbarrows holding 3.6 cu. ft. each, and wheeled in tandem to a steel charging bucket. Two more barrows, each holding 2.7 cu. ft. of gravel, were loaded and also dumped into the charging bucket; then 6 bags of cement (1½ bbls.) were emptied into the bucket. Another bucket was loaded with 21.6 cu. ft. of stone by 8 shovelers. These two buckets were hoisted by a derrick, in rapid succession, and dumped into the mixer. The dump man also attended to supplying water. A charging man started the mixer. The concrete was dumped from the mixer into a skip on a car below, by 2 men who pushed the car out where another derrick on the mixer scow hoisted it to the wall. There were 2 tagmen on each derrick to swing the booms, one paying out a tag rope while the other hauled in. A parapet wall, containing 841 cu. yds., was built in 46 hrs. actual work, 18.2 cu. yds. being placed per hour, each batch containing 1.07 cu. yds. of rammed concrete. A parapet deck, containing 1,720 cu. yds., was built in 88 hrs., or 19½ cu. yds. per hr., each batch being 1.08 cu. yd. The labor cost of making this concrete (common labor being $1.75 per 10 hrs.) was as follows:

	Concrete.	
Loading gang:	Cost, per 10-hr. day.	Cost, per cu. yd.
1 assistant foreman	$ 2.00	$0.011
3 cement handlers	5.25	0.029
3 sand shovelers	5.25	0.029
2 gravel shovelers	3.50	0.020
8 stone shovelers	14.00	0.076
1 hooker-on	1.75	0.010
Mixer gang:		
1 dumpman	1.75	0.010
1 charging man	1.75	0.010
2 car men	3.50	0.020
2 enginemen, at $3.25	6.50	0.035
4 tag men, at $2.00	8.00	0.044
1 fireman	2.00	0.011
Wall gang:		
1 signalman	1.75	0.010
1 dumper	1.75	0.010
6 shovelers, at $2.00	12.00	0.065
4 rammers	7.00	0.038
1 foreman	4.00	0.022
Total (182 cu. yds. per day)	$81.75	$0.450

This cost of 45 cts. per cu. yd. does not include fuel, forms or plant rental.

Cost of Concrete Lock, Upper White River.*—Maj. Graham D. Fitch gives the following:

A lock (No. 1) was built on the Upper White River, at one end of a dam. The lock was built inside a cofferdam, the cost of which is given elsewhere (see index under Cofferdam). Wages of common laborers were $1.50 per 8-hr. day. Work was done by Government forces.

**Engineering-Contracting*, May 6, 1908, p. 279.

The locks are of concrete masonry, 175 ft. long, between hollow quoins. The height of the lock walls is 15 ft. above the upper miter sill, 29 ft. above the lower sill and 30 ft. above the lock floor. Being founded on solid rock, each wall acts separately, and the design is that of a retaining wall. The land wall is slightly stronger than the river wall, but its top is narrow. Opposite the chamber it is stepped in the rear with 1-ft. offsets every 3½ ft., while the river wall is battered. Both walls are 14½ ft. thick at the bottom. At the top the thickness of the river wall is 6 ft., and of the land wall is 4 ft. 9 ins. The ends of the lock walls are necessarily thicker than the side walls of the chamber, as they must not only support the pressure from the gates but also provide work room for the lock tenders. The thickness of the lock walls at the heels of the gates was accordingly made 16 ft. The walls are in conformity with the usual practice, without batter inside. The available length of the lock chamber is 147 ft. and the width is 36 ft. The length of the wall below the lower quoin is 25 ft. and above the upper quoin 37. The total length of the lock is 237 ft.

The hollow quoins are shaped directly in the concrete, a form being used as for any other special surface. The shape is that of an arc of the same radius as the heel of the gate, namely, 10 ins.; they are 110 degrees in length, with tangents at either end 6 ins. long. The gate recesses are 22 ft. long and 2 ft. deep. The miter walls are without batter. Part of the lower miter wall is prolonged downstream to the lower end of the lock, so as to protect the tail bay from being scoured out by the discharge from the culverts.

The upper coffer wall, the function of which is to support a simple movable dam across the head of the lock when the upper gates or valves need repairing, has its sill 1 ft. below the upper miter sill. In coffering the head bay this sill forms the lower support for the needles used, the top support being a trussed beam, the ends of which rest in slots in the main walls at such an elevation that the trussed beam will be as low as possible without being immersed at ordinary low-water stages. A similar arrangement of slot and sill is provided for coffering the tail bay. With the object of preventing the water from cutting behind the land wall, its upper and lower end is, in each lock, provided with a wing wall running perpendicularly back into the bank far enough to join the rocky bluff which is from 20 to 30 ft. in the rear. The thickness of these walls is 4 ft. 9 ins. on top, increasing downward by offsets until rock foundation is reached.

There are two filling culverts each 3 ft. 3 ins. by 7 ft., which are placed in the gate recesses to keep them from filling with mud; these culverts discharge into a large cross culvert in the upper miter wall and thence through 8 small lateral openings into the lock chamber, thus dividing the water into small streams emptying near the lock floor so as to cause little disturbance to boats. For emptying the lock there are two side culverts, each 4 by 5 ft., which pass around the heels of the lower gates entering near the gate re-

cess and discharging below the miter wall into the tail bay, thus serving to prevent deposits there.

The forms used in the concrete work on the lock were of the usual type, namely, plank or lagging laid horizontally and held rigidly by outside posts, solidly braced to the ground so as to prevent the ramming from springing them. Yellow pine lumber was used. The lagging was 2 ins. thick and 12 ins. wide, and was dressed on all four sides. The posts were 4 x 6-in. scantling, spaced 4 ft. apart and were supported at about 8-ft. intervals by inclined braces of 4 x 6-in. scantling. The forms were built in separate alternate sections, the lagging for each section being carried to the full height before concreting was started in that section, and the concreting for each section of wall being completed before another section was begun, as the work was in two 8-hr. shifts, the sections are not monoliths. These posts of the forms were tied together at the top of two rows of ½-in. or ⅝-in. round iron tie-rods. Forms were left in position from four to five days after concreting was completed.

Cost of Forms.—The cost of the forms was as follows:

FORMS.

Materials:	Unit Cost.	Total.	Per M ft.
Lumber, 159 M ft.	$11.40	$1,818	$11.40
Iron and nails	.....	360	2.26
Total		$2,178	$13.66
Labor:			
Inspecting lumber, 15.6 M	.3897	6	.04
Hauling lumber	.....	78	.49
Erecting, etc., 159 M ft.	15.29	2,430	15.29
Total		$2,514	$15.72
Grand total (159 M ft.)		$4,692	$29.38

The total labor time in days in erecting, etc., was 1,218⅝ days, and the work done per man per day was 130.5 ft. B. M.

Mixing.—The concrete mixer was a 4-ft. cubical box of ½-in. riveted steel securely fastened at diagonally opposite corners to a 3-in. steel shaft bored for about half its length with a 1-in. hole for the admission of water. Near one corner was a 15 x 20-in. hinged door for the admission of the dry materials. The mixer was operated by a center crank engine with 6 x 7-in. cylinder and was located on the bank approximately opposite the center of the lock. The concrete was placed by derricks. A Y track led from the mixer parallel to and about 18 ft. back of the land wall to within easy reach of two stiff-leg derricks, so located as to command the entire lock wall. The mixer charge was dumped into skips, which were taken from the cars by derricks and the concrete deposited in place in the lock walls. Upon the completion of the land wall the derricks were placed on this wall, where they commanded the river wall. The concrete was placed in layers 10 ins. thick.

In the concrete work Portland cement only was used, the brands being Lehigh and Alpha. The cement varied in price from $1.82 to

$2.70 per barrel delivered on cars at Birds Point, Mo.; from there it was transported as far as Newport, Ark., over a land-grant railroad, and from Newport to Batesville, the freight charges were approximately 11 cts. per barrel. The sand used was a coarse, sharp, clean sand from the Arkansas River, near Little Rock, and cost 33 cts. per cubic yard delivered at Little Rock. To this sum should be added 26 cts. for freight and 38 cts. for hauling from the Batesville depot to the lock site.

The gravel used was dredged by hired labor, from the river near the works; it consisted of a mixture of pebbles of all sizes with about 19% sand. It was not washed, as bars were found where the gravel contained only clean sand. This river gravel contained usually from 17 to 21% of voids. It cost delivered in bin, including all charges, 35 cts. per cu. yd. The stone used was a sandstone, the so-called bluestone of Cabin Creek, Arkansas, which, tested at Watertown Arsenal, had shown an ultimate strength of 17,700 to 19,700 lbs. per sq. in. It cost 70 cts. per cu. yd. at Cabin Creek; the freight charges amounted to 25 cts. per cu. yd. and the hauling from the depot to the works 60 cts. a cu. yd. All stone was broken into fragments small enough to pass through a 2-in. ring. The voids averaged 51%. The stone was required to be screened, though the run of the crusher would have been preferable.

The proportions of the mix varied, the concrete being richer in the foundations, on exposed surfaces, and when gravel was used. It was the intention to use crushed stone concrete for a depth of 4 ft. on all exposed surfaces and gravel concrete elsewhere, but in the construction of this lock, owing to the irregularity of the delivery of the stone, gravel concrete was used whenever necessary to avoid stopping the work. Three mixtures were used in the walls, depending upon the supply of materials on hand, viz.: 1 part cement, 2½ sand, and 6½ gravel; 1 part cement, 3 sand, 6½ gravel; 1 part cement, 3 sand, 4 gravel and 2 broken stone. Less sand was used with the straight gravel mixture than with the broken stone because of the large per cent of sand contained in the river gravel. The amount of water had to be varied frequently. It was regulated by judgment, according to the appearance of the mortar.

The cost of mixing and placing the concrete for the lock, was as follows:

Materials.	Unit Cost.	Total.	Per cu. yd. Concrete.
Cement, Lehigh, 4,051 bbls.	$2.45	$ 9,925	$1.12
Cement, Lehigh, 841 bbls.	1.97	1,657	.18
Cement, Alpha, 4,992 bbls.	2.20	10,982	1.24
Crushed stone, 2,256 cu. yds.	.70	1,579	.17
Crushed stone, 92 cu. yds.	3.25	299	.03
Sand, 3,096 cu. yds.	.35	1,022	.11
Gravel, 12.9 cu. yds.	.50	6	..
Fuel		537	.06
Illuminating oils		314	.03
Total materials		$26,322	$2.94

Labor.	Unit Cost.	Total.	Per cu. yd. Concrete.
Mixer frame	....	$ 153	$0.017
Insp. of cement, 9,884 bbls	$0.022	223	0.025
Inspect'n of crushed stone, 2,348 cu. yds	.101	238	.026
Insp. of sand, 3,096 cu. yds	.069	212	.024
Storing cement, 2,500 bbls	.079	199	.021
Hauling cement, 9,690 bbls	.08	775	.086
Hauling crushed stone, 2,078 cu. yds	.60	1,247	.140
Hauling sand, 3,053 cu. yds	.38	1,160	.130
Dredging gravel, 6,125 cu. yds	.105	646	.072
Unloading gravel for hand mixed concrete, 385 cu. yds	.181	70	.008
Hoisting gravel for machine mixed concrete, 5,025 cu. yds	.473	2,378	.266
Mixing and placing machine mixed concrete, 7,858 cu. yds	.568	4,464	.499
Mixing and placing hand mixed concrete, 1,081 cu. yds	1.83	1,981	.221
Tamping machine mixed concrete, 7,858 cu. yds	.328	2,581	.288
Tamping hand mixed concrete, 1,081 cu. yds	.443	479	.053
Finishing top of lock wall, 548 cu. yds	.104	57	.006
Total labor		$16,864	$1.88
Grand total, 8,939 cu. yds. concrete		$43,186	$4.83
Cost of concrete, including forms		$5.36 per cu. yd.	

Some of the labor items can be further summarized as follows:

	Work done bbls.	Labor time in days.	Work done per man per day. bbls.
Inspection of cement	9,884	73 6/8	139.21
Storing cement	2,500	94 5/8	26.32
	cu. yds.		cu. yds.
Inspection of crushed stone	2,348	71	21.15
Inspection of sand	3,096	111	23.63
Dredging gravel	6,125	306 2/8	20
Unloading gravel for hand mixed concrete	385	41	9.39
Hoisting gravel for machine mixed concrete	5,025	1,308	3.84
Mixing and placing machine mixed concrete	7,858	2,384 3/8	3.29
Mixing and placing hand mixed concrete	1,081	1,103 4/8	.98
Tamping machine mixed concrete	7,858	1,420 1/8	5.53
Tamping hand mixed concrete	1,081	283	3.82
Finishing top of lock wall	548	29 5/8	18.27

Valves, Ladders, Etc.—The valves in the culverts previously mentioned, are butterfly or balanced valves of steel plates and angles turning on vertical shafts. There are two valves to each filling culvert because the valves had to be of low height in order to remain submerged during low water. They are 3 ft. 2 ins. by 3 ft. 2 ins. in size. The wicket is set in a cast iron frame bolted to the concrete and is protected from debris by a movable screen sliding vertically in guides bolted to the walls. The valve operating gear, which is set in a covered recess in the coping, consists of a gear sector keyed to the top of the valve shaft and geared with a pinion turned by a rachet wrench and wheel. Two recessed ladders are placed in each chamber wall of the lock.

The cost of the valves, ladders, etc., was as follows:

Materials.	Unit Cost.	Total.
New valves and foundry work on same, 2	$267.00	$ 534
Iron, wrought, 5,397 lbs.	.06	324
Iron, cast, 7,737 lbs.	.045	348
Steel, 6,976 lbs.	.065	543
Total materials		$1,749
Labor.		
Hauling, iron, etc.	...	$16
Placing 20,110 lbs.	$0.02	406
Total labor		$ 422
Grand total		2,171

Summary of Lock Work:

	Total.	Unit Cost.
Clearing site (4 acres)	$ 204	$51.00
Cofferdam (462 lin. ft.)	8,487	18.37
Excavation (3,635 cu. yds.)	5,758	1.58
Forms (159 M. ft.)	4,692	29.38
Concrete (8,939 cu. yds.)	43,186	4.83
Gates and sills	5,569	....
Valves, ladders, etc.	2,171	....
Filling behind land wall (4,262 cu. yds.)	3,441	.805
Grading and paving same (1,916 sq. yds.)	1,553	.810
Excavating upper approach	388	....
Excavating lower approach	182	....
Upper land crib (30 M. ft.)	1,713	57.10
Lower land crib (9.3 M. ft.)	806	86.66
Lower river crib (46.2 M. ft.)	2,804	60.69
Upper river crib (47.6 M. ft.)	2,761	58.00
Total	$84,715	

For the cost of the lock gates, see the section on Timberwork and Piling. Consult the index under "Timberwork, Lock Gates."

Cost of Concrete Locks, Coosa River, Ala.—Mr. Charles Firth gives the following on the concrete locks on the Coosa River, Ala. Lock No. 31 has a length of 322 ft. between hollow quoins and a length of 420 ft. over all, with a width of 52 ft. in the clear. The lock walls are 34.7 ft. high and 16 ft. thick at the base The total quantity of concrete was 20,000 cu. yds., requiring 21,500 bbls. of cement, half Atlas and half Alsen's. It was mixed 1:3:5½, the stone being crushed mica-schist. Two mechanical 4-ft. cube mixers were used, being driven by a 10 × 16 engine. Each batch consisted of 3 cu. ft. cement, 9 cu. ft. sand and 16½ cu. ft. stone, and was turned 4 times before and 6 times after adding the water, at a speed not exceeding 8 revolutions per minute. The top floor of the mixing house had a storage capacity of 2,000 bbls. of cement. The sand and stone were delivered in side dump-cars. The concrete was delivered into bottom-dump cars. The average output of these two mixers was 200 cu. yds. in 8 hrs., or 100 cu. yds. per mixer, but it was limited by the means of placing the concrete. Each batch of concrete measured 24 cu. ft. in the car, but it shrank 20% when rammed in place, so that it required 34 cu. ft. of concrete in the cars to make 1 cu. yd. in place. The concrete was mixed quite dry and rammed in 6 to 8-in. layers, using 30-lb. iron rammers having a square face 6 ins. on a side. On all exposed surfaces a 1:3 mortar was placed as the work progressed, making a thickness of 6 ins. of mortar. To

do this 2 × 12-in. planks were placed 4 ins. away from the forms, being kept at that distance by 2 × 4-in. strips of wood. After the backing concrete was in place and partly rammed, these planks were removed and the 6-in. space filled with mortar. The walls were carried up in lifts, each lift being completed all around the dock before the next was commenced. The first was 10.7 ft. high; each succeeding lift was 6 ft., except the last which was 4.5 ft., exclusive of the 18-in. coping. The coping was 5 ft. wide and made in separate blocks 3 ft. long, which were placed after the walls were completed. The coping was 1:2:3 concrete, faced with 1:1 mortar, and was cast in blocks face down, its edges being rounded to a 3-in. radius. The sides of the molds for these blocks were removed 3 days after making, and 10 days later the blocks were stacked away.

In building the forms 6 × 8-in. posts 24 ft. long were set up on the inside of the lock in line, 5 ft. 7 ins. apart; and a similar row of posts 12 ft. long was set up outside of the lock. The posts were capped with 6 × 8-in. caps which supported the track stringers for the concrete cars. Each line of posts was sheeted with 3 × 10-in. plank dressed on all sides, and the posts were well braced with inclined struts. After the first lift was completed, the back row of posts was lifted onto the offset on the back of the wall by the reduced width of the next lift; but the long posts on the front face were not moved, the caps being simply unbolted from them and fastened near the top of the posts. The sheeting plank was of course moved up. No tie bolts were built into the concrete wall, which made the bracing of the forms rather elaborate as the wall grew higher.

The bottom-dump concrete cars were dumped onto wooden platforms inside the forms, as it was found that even a slight drop caused the larger stones to separate and roll to the outer edges. These stones were shoveled back into the pile, and then the concrete was placed with shovels. The doors of the cars were hung at the sides, and upon dumping they would strike the stringers carrying the track, thus jarring the forms and frequently throwing them out of line. A better method would have been to have hinged the doors at each end of the car. It was found advisable to have plenty of head room at the end of each lift, otherwise the spreading and ramming were not properly done. During the year ending June, 1895, there were only 90 days when work was carried on uninterrupted by floods. The total quantity of concrete placed that year was 8,710 cu. yds., the work being done by day laborers for the Government (not by contract). Negroes at $1 per 8-hr. day were employed. The cost per cubic yard of 1:3:5½ concrete was as follows:

1 bbl. cement	$2.48
0.88 cu. yd. stone, at $0.76	.67
0.36 cu. yd. sand at $0.34	.12
Mixing, placing and ramming	.88
Staging and forms	.42
Total, per cu. yd.	$4.57

Had wages been $1.50 per day the cost would have been $1.32 per cu. yd. instead of 88 cts. for mixing.

Cost of Locks, Cascade Canal.—In Gillette and Hill's "Concrete Construction," Chapter XI, on "Fortifications, Locks, Dams and Breakwaters," the methods of building and detailed costs are given. It will suffice here to state that the cost was $8 per cu. yd. for machine mixed concrete, and $9 for hand mixed concrete, of which cost $5.50 was for materials, and $1.70 for plant and superintendence.

Cost of Locks, Ill. and Miss. Canal.—In Gillette and Hill's "Concrete Construction, pp. 196 to 197; a detailed illustrated description is given of the forms, plant, and methods of building these locks. The cost of two of the locks was $9 per cu. yd., of which $2 to $2.40 was labor and carpenter work. Cube mixers were used. For detailed costs consult the above reference.

Labor Cost of Retaining Walls.—In canal excavation, in subway work in cities, and the like, it is often necessary to dig trenches and build retaining walls in the trenches before excavating the core of earth between the walls. The following example of this class of work is taken from some records that I have: A Smith mixer was used, the concrete being delivered where wanted by a Lambert cableway of 400 ft. span. The broken stone and sand were delivered near the work in hopper-bottom cars which were dumped through a trestle onto a plank floor. Men loaded the material into one-horse dump carts which hauled it 900 ft. to the mixer platform. This platform was 24 × 24 ft. square, and 5 ft. high, with a planked approach 40 ft. long and contained 7,500 ft. B. M. The stone and sand were dumped at the mouth of the mixer and shoveled in by 4 men. Eight men, working in pairs, loaded the broken stone into the carts, and 2 men loaded the sand. Each cart was loaded with about 70 shovelfuls of stone on top of which 35 shovelfuls of sand were thrown. It took 3 to 5 mins. to load on the stone and 1 min. to load the sand. The carts traveled very slowly, about 150 ft. a minute—in fact, all the men on the job, including the cart drivers, were slow. After mixing, the concrete was dumped into iron buckets holding 14 cu. ft. water measure, making about ½ cu. yd. in a batch. The buckets were hooked on to the cableway and conveyed where wanted in the wall. Steam for running the mixer was taken from the same boiler that supplied the cableway engine. The average output of this plant was 100 cu. yds. of concrete per 10-hr. day, although on many days the output was 125 cu. yds., or 250 batches. The cost of mixing and placing was as follows, on a basis of 100 cu. yds. per day:

	Per day.	Per cu. yd.
8 men loading stone into carts........	$ 12.00	$ .12
2 men loading sand into carts.........	3.00	.03
1 cart hauling cement.................	3.00	.03
8 carts hauling stone and sand........	24.00	.24
4 men loading mixer...................	6.00	.06
1 man dumping mixer...................	1.50	.01
2 men handling buckets at mixer.....	3.00	.03
6 men dumping buckets and ramming	9.00	.09
12 men making forms at $2.50.......	30.00	.30

1 cable engineman	3.00	.03
1 fireman	2.00	.02
1 foreman	6.00	.06
1 water-boy	1.00	.01
1 ton coal for cableway and mixer	4.00	.04
Total	$107.50	$1.07

In addition to this cost of $1.07 per cu. yd. there was the cost of moving the whole plant for every 350 ft. of wall. This required 2 days, at a cost of $100, and as there were about 1,000 cu. yds. of concrete in 350 ft. of wall 16 ft. high, the cost of moving the plant was 10 cts. per cu. yd. of concrete, bringing the total cost of mixing and placing up to 87 cts. per cu. yd. As above stated, the whole gang was slow.

The labor cost of making the forms was high, for such simple and heavy work, costing $10 per M. of lumber placed each day. The forms were 2-in. sheeting plank held by 4 × 6-in. upright studs 2½ ft. apart, which were braced against the sides of the trench. The face of the forms was dressed lumber and all cracks were carefully puttied and sandpapered.

The above costs relate only to the massive part of the wall and not the cost of putting in the facing mortar, which was excessively high. The face mortar was 2 ins. thick, and about 3½ cu. yds. of it were placed each day with a force of 8 men! Two of these men mixed the mortar, 2 men wheeled it in barrows to the wall, 2 men lowered it in buckets, and 2 men put it in place on the face of the wall. If we distribute this labor cost on the face mortar over the 100 cu. yds. of concrete laid each day, we have another 12 cts. per cu. yd.; but a better way is to regard this work as a separate item, and estimate it as square feet of facing work. In that case these 8 men did 500 sq. ft. of facing work per day at a cost of nearly 2½ cts. per sq. ft. for labor.

The building of a wall similar to the one just described was done by another gang as follows: The stone and sand were delivered in flat cars provided with side boards. In a stone car 5 men were kept busy shoveling stone into iron dump buckets having a capacity of 20 cu. ft. water measure. Each bucket was filled about two-thirds full of stone, then it was picked up by a derrick and swung over to the next car which contained sand, where two men filled the remaining third of the bucket with sand. The bucket was then lifted and swung by the derrick over to the platform of the mixer where it was dumped and its contents shoveled by four men into the mixer, cement being added by these men. The mixer was dumped by two men, loading iron buckets holding about ½ cu. yd. of concrete each, which was the size of each batch. A second derrick picked up the concrete bucket and swung it over to a platform where it was dumped by one man; then ten men loaded the concrete into wheelbarrows and wheeled it along a runway to the wall. One man assisted each barrow in dumping into a hopper on the top of a sheet-iron pipe which delivered the concrete. The two derricks were stiff-leg derricks with 40-ft. booms, provided

with bull-wheels, and operated by double cylinder (7 × 10-in.) engines of 18 hp. each. About 1 ton of coal was burned daily under the boiler supplying steam to these two hoisting engines. The output of this plant was 200 batches or 100 cu. yds. of concrete per 10-hr. day, when materials were promptly supplied by the railroad; but delays in delivering cars ran the average output down to 80 cu. yds. per day.

On the basis of 100 cu. yds. daily output, the cost of mixing and placing the concrete was as follows:

	Per day.	Per cu. yd.
5 men loading stone	$ 7.50	$0.07½
2 men loading sand	3.00	.03
4 men charging mixer	6.00	.06
2 men loading concrete into buckets	3.00	.03
1 man dumping concrete from buckets	1.50	.01½
10 men loading and wheeling concrete	15.00	.15
1 man dumping wheelbarrows	1.50	.01½
3 men spreading and ramming	4.50	.04½
2 enginemen	5.00	.05
1 fireman	2.00	.02
1 water-boy	1.00	.01
1 foreman	6.00	.06
10 men making forms	25.00	.25
1 ton coal	4.00	.04
Total	$85.00	$0.85

In addition there were 8 men engaged in mixing and placing the 2-in. facing of mortar as stated above.

Cost of Retaining Walls, Chicago Drainage Canal.—Mr. James W. Beardsley gives the following data on 20,000 lin. ft. of concrete wall, built by contract. The work was let in two sections, Secs. 14 and 15, which will be considered separately. In both cases a 1:1½:4 natural cement concrete was used, and it was faced with 1:3 Portland mortar 3 ins. thick, also coped with the same 3 ins. thick. The average height of the wall was 10 ft. on Sec. 14, and 22 ft. on Sec. 15, the thickness at the base being half the height.

On Sec. 14, the stone for the concrete was obtained from the spoil bank of the canal, loaded into wheelbarrows and wheeled about 100 ft. to the crusher; some was hauled in wagons. An Austin jaw crusher was used, and it discharged the stone into bins from which it was fed into a Sooysmith mixer. The crusher and the mixer were mounted on a flat car. Bucket elevators were used to raise the stone, sand and cement from their bins to the mixer; the buckets were made of such size as to give the proper proportions of ingredients, as they all traveled at the same speed. Only two laborers were required to look after the elevators. The sand and cement were hauled by teams and dumped into the receiving bins. There were 23,568 cu. yds. on Sec. 14, and the cost was as follows:

General force.	Typical force.	Wages per 10 hrs.	Cost per cu. yd.
Superintendent	1.0	$5.00	$0.026
Blacksmith	1.1	2.75	0.016
Timekeeper	0.5	2.50	0.007
Watchman	0.6	2.00	0.007
Waterboys	3.9	1.00	0.022

Wall force.			
Foreman	0.9	2.50	0.013
Laborers	8.6	1.50	0.073
Tampers	2.3	1.75	0.022
Mixer force.			
Foreman	1.2	2.50	0.017
Enginemen	1.8	2.50	0.025
Laborers	6.7	1.50	0.057
Pump runner	1.0	2.00	0.010
Mixing machines	1.7	1.25	0.012
Timber force.			
Foreman	0.6	2.50	0.008
Carpenters	4.7	2.50	0.057
Laborers	1.2	1.50	0.010
Helpers	5.3	2.50	0.075
Hauling force.			
Laborers	2.6	1.75	0.026
Teams	6.3	3.25	0.116
Crushing force.			
Foreman	0.5	$2.50	$0.007
Engineman	1.7	2.50	0.023
Laborers	3.5	1.50	0.032
Austin crushers	1.7	1.20	0.011
Loading stone.			
Foreman	1.7	2.50	0.023
Laborers	32.9	1.50	0.280
Total for crushing, mixing and placing			$0.975

The daily costs charged to the mixers and crushers include the cost of coal, at $2 a ton, and the cost of oil.

The gang "loading stone" apparently did a good deal of sledging of large stones, and they also wheeled a large part of it in barrows to the crusher.

The plant cost $9,600, distributed as follows:

2 jaw crushers	$3,000
2 mixers	3,000
Track	1,260
Lumber	500
Pipe	840
Sheds	400
Pumps	600
Total	$9,600

If this first cost of the plant were distributed over the 23,658 cu. yds. of concrete it would amount to 41 cts. per cu. yd.

The cost of the concrete was as follows:

	Per cu. yd.
Utica cement, at $0.65 per bbl	$0.863
Portland cement, at $2.25 per bbl	0.305
Sand, at $1.35 per cu. yd	0.465
Stone and labor, as above given	0.975
Total	$2.608
First cost of plant	$0.407

On Sec. 15 the conditions were much the same as on Sec. 14, just described, except that the limestone was quarried from the bed of the canal, and was crushed in a stationary crusher, No. 7 Gates. The stone was hauled 1,000 ft. to the crusher on cars drawn by a

cable from a hoisting engine. The output of this crusher averaged 210 cu. yds. per day of 10 hrs. The crushed stone was hauled in dump cars, drawn by a locomotive, to the mixers. Spiral screw mixers mounted on flat cars were used, and they delivered the concrete to belt conveyors which delivered the concrete into the forms.

The forms on Sec. 15 (and on Sec. 14 as well) consisted of upright posts set 8 ft. apart and 9 ins. in front of the wall, held at the toe by iron dowels driven into holes in the rock, and held to the rear posts by the rods. The plank sheeting was made up in panels 2 ft. wide and 16 ft. long, and was held up temporarily by loose rings which passed around the posts which were gripped by the friction of the rings. These panels were brought to proper line and held in place by wooden wedges. After the concrete had set 24 hrs. the wedges were struck, the panels removed and scraped clean ready to be used again.

The cost of quarrying and crushing the stone, and mixing the concrete on Sec. 15 was as follows:

General force.	Typical force.	Wages per 10 hrs.	Cost per cu. yd.
Superintendent	1.0	$5.00	$0.024
Blacksmith	0.9	2.75	0.011
Teams	1.7	3.00	0.025
Waterboy	4.5	1.00	0.022
Wall force.			
Foreman	1.1	2.50	0.010
Laborers	14.4	1.50	0.105
Tampers	0.1	1.75	0.001
Mixer force.			
Foreman	2.1	2.50	0.026
Enginemen	2.1	2.50	0.022
Laborers	23.1	1.50	0.180
Mixing machines	2.1	1.25	0.022
Timber force.			
Carpenters	0.8	3.00	0.013
Laborers	0.7	1.50	0.005
Helpers	10.2	2.50	0.125
Hauling force.			
Foreman	0.7	2.50	0.009
Enginemen	1.4	2.50	0.019
Fireman	0.4	1.75	0.003
Brakeman	2.2	2.00	0.018
Teams	0.4	3.25	0.007
Laborers	1.5	1.50	0.010
Locomotives	1.4	2.25	0.015
Crushing force.			
Foreman	1.0	2.50	0.014
Enginemen	1.0	2.50	0.014
Laborers	11.1	1.50	0.081
Firemen	1.0	1.75	0.008
Gyratory crusher	1.0	2.25	0.011
Quarry force.			
Foreman	1.2	2.50	0.012
Laborers	19.0	1.50	0.140
Drillers	1.8	2.00	0.017
Drill helpers	1.8	1.50	0.013
Machine drills	1.8	1.25	0.011
Total			$0.993

The first cost of the plant for this work on Sec. 15 was $25,420, distributed as follows:

1 crusher, No. 7 Gates	$12,000
Use of locomotive	2,200
Cars and track	5,300
3 mixers	3,000
Lumber	1,200
Pipe	720
Small tools	1,000
Total	$25,420

This $25,420 distributed over the 44,811 cu. yds. of concrete amounts to 57 cts. per cu. yd.

It will be noted that 2 mixers were kept busy. Their average output was 100 cu. yds. each per day, which is the same as for the mixers on Sec. 14.

The total cost of concrete on Sec. 15 was as follows:

	Per cu. yd.
Labor quarrying, crushing and mixing	$0.991
Explosives	0.083
Utica cement, at $0.60 per bbl	0.930
Portland cement, at $2.25 per bbl	0.180
Sand, at $1.35 per cu. yd	0.476
Total	$2.660
First cost of plant	$0.567

It is not strictly correct to charge the full first cost of the plant to the work as it possessed considerable salvage value at the end.

For the purpose of comparing Secs. 14 and 15 the following summary is given of the cost per cubic yard of concrete:

	Sec. 14.	Sec. 15.
General force	$0.078	$0.082
Wall force	0.108	0.116
Mixing force	0.121	0.250
Timbering force	0.150	0.140
Hauling force	0.142	0.081
Crushing force	0.073	0.128
Quarry force	0.303	0.275
Cement, natural	0.863	0.930
Cement, Portland	0.305	0.180
Sand	0.465	0.476
Plant (full cost)	0.407	0.567
Total	$3.015	$3.225

It should be remembered that on Sec. 14 there was no drilling and blasting of the rock, but that the "quarry force" not only loaded but hauled the stone to the crusher. The cost of mixing on Sec. 15 is higher than on Sec. 14 because the materials were dumped on platforms and shoveled into the mixer, instead of being discharged from bins into the mixer as on Sec. 14.

Cost of a Retaining Wall.—For building a retaining wall 7 ft. high, forms were made and placed by a carpenter and helper at $8 per M., wages being 35 cts. and 20 cts. an hour, respectively. Concrete materials were dumped from wagons alongside the mixing board. Ramming was unusually thorough. Foreman expense was

high, due to small number in gang; 2 cu. yds. were laid per hour by the gang.

	Per day.	Per cu. yd.
7 mixers, 15 cts. per hr.	$10.50	$0.53
2 rammers, 15 cts. per hr.	3.00	0.15
1 foreman, 30 cts. per hr., and 1 water boy, 5 cts.	3.50	0.17
Total labor	$17.00	$0.85

The total cost was as follows per cubic yard:

	Per cu. yd.
0.8 bbls. Portland cement, at $2	$1.60
Sand	0.30
Gravel	0.70
Labor mixing and placing	0.85
Lumber for forms, at $16 per M.	0.56
Labor on forms, at $8 per M.	0.28
Total, per cu. yd.	$4.29

The sheathing plank for the forms was 2-in. hemlock.

Cost of Retaining Walls, Reference.—Different methods of building walls, designs of forms, plant, etc., together with costs are given in "Concrete Construction," by Gillette and Hill.

Cost of Filling Pier Cylinders With Concrete.—In this case the gravel and sand forming the concrete were wheeled in barrows a distance of 100 ft. to the mixing-board at the foot of steel pier cylinders, into which concrete was dumped after raising it 20 ft. in wooden skips. Two cu. yds. concrete laid per hour by the gang.

	Per day.	Per cu. yd.
6 men wheeling materials and mixing, 15 cts. per hr.	$ 9.00	$0.45
2 men dumping skips and ramming, 15 cts. per hr.	3.00	0.15
1 team and driver, at 40 cts. per hr.	4.00	0.20
1 foreman, at 30 cts. per hr.	3.00	0.15
Total	$19.00	$0.95

Had the job been larger, more men would have been employed to reduce the fixed expense of team time, for a team can readily raise 10 cu. yds. an hour, using a mast, or ginpole, with block and tackle. The foreman worked on the mixing-board himself. The concrete was perfectly mixed. The men worked with great energy.

Cost of Concrete Harbor Pier, Superior Entry, Wis.—For cuts showing cross-section of this pier, the forms used in its construction, and bucket used in depositing concrete under water, see Gillette and Hill's "Concrete Construction."

The pier is 3,023 ft. long at Superior Entry, Wis. The work was done by day labor for the Government, under the direction of Mr. Clarence Coleman, U. S. Assistant Engineer.

About 80% of the concrete was deposited in molds under water, according to a plan devised in 1902 by Maj. D. D. Gaillard, Corps of Engineers. The molds consisted of bottomless boxes, built in four pieces, two sides and two end pieces, held together by 1¼-in. turnbuckle tie-rods. Cast-iron weights were attached to the molds to

overcome the buoyancy of the timber. The concrete was built in place, in two tiers of blocks, the lower tier resting directly on piles and entirely under water. The upper tier of blocks was almost entirely above water. A pile trestle was built on each side of the proposed pier, and a traveler for raising and lowering the molds, spanned the gap between the two trestles. After the mold for a block of concrete had been placed on the bottom, it was filled with concrete lowered in a bucket with a drop bottom. Twelve of these buckets were used, and were hauled from the mixer on cars to a locomotive crane, which lifted each bucket from the car and lowered it to place. The locomotive crane was elevated on a gantry frame so that a train of cars on the same trestle could pass directly under it without interference. This enabled two of these locomotive cranes to work on the same trestle.

Each concrete bucket was provided with two 12-oz. canvas curtains or covers each 3 × 4 ft., quilted with 110 pieces of 1/16 × 1 × 3-in. sheet-lead. The curtains were fastened, one to each side of the top of the bucket, and were folded over the concrete so as to cover it completely and protect it from wash while being lowered through the water. Occasionally, when an opportunity occurred to allow the top of the concrete in a bucket to be examined after being lowered and raised through 23 ft. of water, the concrete was invariably found in good condition. Discoloration of the water from cement was seldom noticed during the descent of the bucket. The concrete for this subaqueous work was mixed quite wet.

The pebbles for the concrete were delivered by contract, and were unloaded from the scows by means of a clam-shell bucket into a hopper. This hopper fed the pebbles on to an endless conveyor which delivered them to a rotary screen. Inside this screen water was discharged under a pressure from a 4-in. pipe, to wash the pebbles. From the screen the pebbles passed through a chute into 4-yd. cars, which were hauled up an incline to a height of 65 ft. by means of a hoisting engine. The cars were dumped automatically, forming a stock pile. Under the stock pile was a double gallery or tunnel, provided with eight chutes through the roof; and from these chutes the cars were loaded and hauled by a hoisting engine up an inclined trestle to the bins above the concrete mixer. A system of electric bell signals was used in handling these cars.

The sand was handled from the stock pile in the same manner. The cement was loaded in bags on a car at the warehouse, hauled to the mixer and elevated by a sprocket-chain elevator.

Chutes from the bins delivered the materials into the concrete mixer which was of the modified cubical type revolving on trunnions about an axial line through diagonal corners of the cube (made by the Municipal Engineering and Contracting Co., Chicago, Ill.). It was driven by a 7 × 10-in. vertical single engine with boiler. The mixer demonstrated its ability to turn out a batch of perfectly mixed concrete every 1⅓ mins. It discharged into a hopper, provided with a cut-off chute, which discharged into the concrete

buckets on the cars. Four buckets of concrete were hauled in a train by a locomotive to their destination. There were two locomotives and 23 cars.

In the operation of this plant 55 men were employed, 43 being engaged on actual concrete work and 12 building molds and appliances for future work. The work was done by day labor for the Government, and the cost of operation was as follows for one typical week when, in 6 days of 8 hours each, the output was 1,383 cu. yds., or an average of 230 cu. yds. per day. The output on one day was considerably below the average on account of an accident to plant but this may be considered as typical.

	Per cu. yd.
Pebbles from stock pile to mixer.	
4 laborers, at $2	$0.0348
1 engineman, at $3	0.0131
Coal, oil and waste, at $1.03	0.0043
Sand from stock pile to mixer.	
5 laborers, at $2	0.0434
1 engineman, at $2.50	0.0109
Coal, oil and waste, at $0.82	0.0035
Cement from warehouse to mixer.	
5 laborers, at $2	0.0434
Mixing concrete.	
1 engineman, at $2.50	0.0109
1 mechanic, at $2.50	0.0108
Coal, oil and waste, at $1.29	0.0056
Transporting concrete.	
4 laborers, at $2	0.0348
1 engineman, at $3	0.0130
Coal, oil and waste, at $0.66	0.0028
Depositing concrete in molds.	
4 laborers, at $2	0.0348
1 engineman, at $3	0.0130
1 rigger, at $3	0.0130
Coal, oil and waste, at $1.18	0.0051
Assembling, transporting, setting and removing molds.	
4 laborers, at $2	0.0347
1 engineman, at $3.25	0.0141
1 carpenter, at $3	0.0130
1 mechanic, at $2.50	0.0109
Coal, oil and waste, at $1.39	0.0060
Care of tracks.	
1 laborer, at $2	0.0086
1 mechanic, at $2.50	0.0109
Supplying coal.	
3 laborers, at $2	0.0260
Blacksmith work.	
1 laborer, at $2	0.0086
1 blacksmith, at $3.25	0.0141
Water boy, at $0.75	0.0032
Total per cu. yd.	$0.4473
Add 75% of the cost of administration	0.1388
Total labor per cu. yd.	$0.5861

The total cost of each cubic yard of concrete in place is estimated to be as follows:

	Per cu. yd.
Ten-elevenths cu. yd. pebbles, at $1.085	$0.9864
Ten-twenty-seconds cu. yd. sand, at $0.00	0.0000
1.26 bbls. cement, at $1.77	2.2302
Labor, as above given	0.5861
Cost of plant distributed over total average	0.8400
Total yardage	$4.6427

It will be noticed that the sand cost nothing, as it was dredged from the trench in which the pier was built, and paid for as dredging. The cost of the plant was distributed over the South Pier work and over the proposed North Pier work, on the basis of only 20% salvage value after the completion of both piers. It is said, however, that 80% is too high an allowance for the probable depreciation.

The cost of the trestles was included in the cost of the plant. The Washington fir used in the trestles cost $16 per M. delivered in the yard. The cost of framing and placing the timberwork (exclusive of the piles) was $3.25 per M.

The cost of the plant was as follows:

Machinery	$30,055.98
Piles and pile driving	13,963.00
Lumber for trestles and molds	12,094.26
Iron and castings	7,572.36
Labor on plant	15,760.40
Total	$79,446.00

The item of "labor on plant" includes all work in building trestles, laying track, building molds, mold traveler and all appurtenances for performing the work. The cost of plant per cu. yd. of concrete was estimated thus:

First cost	$79,446
20% depreciation during use on South Pier	15,889
Estimated increase in size of plant for use on North Pier	3,972
Total for both piers	$99,307
Salvage value of plant 20%	19,861
Net	$79,446

$79,446 ÷ 94,000 cu. yds. = $0.84 per cu. yd.

The proportions of the subaqueous concrete were 1:2.5:5 by volume, or 1:2.73:5.78 by weight, cement being assumed to weigh 100 lbs. per cu. ft. The proportions of the superaqueous concrete were 1:3.12:6.25 by volume, or 1:3.41:7.22 by weight. The dry sand weighed 109.2 lbs. per cu. ft., the voids being 35.1%. The pebbles weighed 115.5 lbs. per cu. ft., the voids being 31%.

As above stated, the molds were bottomless boxes built in four pieces, two sides and two ends, held together by tie-rods. The 1¼-in. turnbuckle tie-rods passed through the ends of beams that bore against the outside of the mold. These tie-rods had eyes at each end, in which rods with wedge shaped ends were inserted. The mold was erected on the trestle by the locomotive crane, and

was then lifted by the mold traveler, carried and lowered to place. The largest one of these molds, with its cast-iron ballast, weighed 40 tons. When it was desired to remove a mold, after the concrete block had hardened, the nuts on the wedge-ended rods were turned, thus pulling the wedge end from the eye of the tie-rod, and releasing the sides of the mold from the ends. The locomotive crane then raised the sides and ends separately and assembled them ready to be lowered again for the next block. The time required to remove one of these 40-ton molds, reassemble and set it again rarely exceeded 60 mins., and had been accomplished in 45 mins.

As already stated, the concrete was built in alternate blocks; then the intermediate blocks were built, the ends of the concrete blocks just built serving as end molds for the new blocks. The two sides of the mold (without the end pieces) were assembled by the aid of templates, and were bolted together by tie-rods. To hold the sides apart when the templates were removed, it was necessary to surround each of the six tie-rods with a box of 1-in. plank. These boxes measured 4 ins. square on the inside; and were left buried in the concrete. Their purpose was to act as horizontal struts to hold the sides of the mold apart, and to permit removal of the tie-rods after the concrete block had been built. The removal of these rods was accomplished by withdrawing the wedge-ended rods.

The mold traveler deserves a brief description. It was provided with a four-drum engine, and the drums were actuated by a worm gear which was positive in its movement in lowering as well as in raising. The drums act independently or together, as desired. The hoisting speed was 6 ft. per min., and the traveling speed, 100 ft. per min. The load was suspended on four hooks, depending by double blocks and ⅝-in. wire ropes from four trolleys suspended from the truss, which allowed lateral adjustment of the mold. The difficulty of using so broad a gage as 31 ft., on a curve having a radius of 563 ft., was overcome by using a differential gear in the driving shaft of the propelling gear, thus compensating for the greater distance traveled by the wheels on the outer rail. The whole machine was carried on six trucks having two double-flanged wheels each. The four forward trucks were swiveled on steel bed plates with 3-in. king bolts. The two rear trucks were fixed to the chord and had idler wheels, which slid on their axles so as to accommodate themselves to the curve.

Rubble Concrete Data.—By some engineers it is believed that rubble concrete, particularly for dam construction, is a very new form of masonry. In Trans. Am. Soc. C. E., 1875, Mr. J. J. R. Croes describes work on the Boyd's Corner Dam on the Croton River, near New York. This work was begun in 1867, and for a time rubble concrete was used, but was finally discontinued, due to the impression that it might not be water-tight. In those days "sloppy" concrete would not have been allowed, which probably accounts for the difficulty of getting a water-tight rubble concrete. The specifications called for a dry concrete that had to be thoroughly rammed in between the rubble stones; and, to give room for this ramming, the

contractor was not permitted to lay any two stones closer together than 12 ins. As a result, not more than 33% of the masonry was rubble stones, the rest being the concrete between the stones. Mr. Croes states that most of the bidders erred in assuming that 66% to 75% of the masonry would be rubble stones.

The form of the rubble stones as they come from the quarry should be considered. Stones that have flat beds, like many sandstones and limestones, can be laid upon layers of "dry" concrete; and can have their vertical joints readily filled with concrete rammed into place. But granites and other stones that break out irregularly, can not be well bedded in concrete unless it is made so soft as to be "sloppy." In thin retaining walls, small, irregular stones may be forced into concrete by jumping upon them, men wearing rubber boots.

When stones come out flat bedded, if it is desired to economize cement, make the bed joints of ordinary mortar (not concrete) and fill the vertical joints with concrete.

Generally it is an absurd practice to break up large blocks of stone in a crusher for the purpose of making the whole of a heavy wall of concrete, since rubble concrete requires not only less cement but effects a saving in crushing. There are exceptions, however. For example, the anchorages of the Manhattan Bridge in New York City were specified to be of rubble concrete, doubtless because the designer believed this sort of masonry to be cheaper than concrete. In this case an economic mistake was made, for all the rubble stone must be quarried up the Hudson River, loaded into scows, unloaded onto cars, and finally unloaded and delivered by derricks. This repeated handling of large, irregular rubble stones is so expensive that it more than offsets the cost of crushing, as well as the extra cost of cement in plain concrete. Crushed stone can be unloaded from boats by means of clam-shell buckets at a low cost (see data in the section on Rock Excavation). It can be transported on a belt conveyor, elevated in a bucket conveyor, mixed with sand and cement, and delivered to the work, all with very little manual labor where the installation of a very efficient plant is justified by the magnitude of the job. Large rubble stones, on the other hand, can not be handled so cheaply nor with as great rapidity as crushed stone. Each particular piece of work, therefore, must be treated as a separate problem in engineering economics; for no unqualified generalization as to the relative cheapness of this or that kind of masonry is to be relied upon.

In the construction of a dry dock at the Charleston Navy Yard, rubble concrete was used. The rubble stones averaged about ½ cu. yd. each, and were spaced about 18 ins. apart. About 67% of the masonry was 1:2:5 concrete, leaving 33% of rubble stones.

The Spier Falls Dam on the upper Hudson River is of cyclopean masonry, the rubble stones being very large pieces of granite, which are bedded in 1:2½:5 concrete. At the time of my visit to the dam, it was estimated that about 33% of the masonry was

concrete. I have recently been informed by Mr. C. E. Parsons, the chief engineer, that about 1 bbl. of cement was used in each cubic yard of masonry. This high percentage of cement may be accounted for by the fact that there was a good deal of plain rubble laid in 1:2 cement mortar, no accurate record of which was kept. At the time of my visit, three Ransome mixers were being used, two for concrete and one for mortar. Each concrete mixer averaged 200 batches in 10 hrs., of 23 cu. ft. of concrete per batch. I am inclined to think, from inspection of the masonry during the time it was being laid, that about 40% of the dam was rubble stones and the remaining 60% was concrete and mortar. The stones and concrete were delivered by cableways to stiff-leg derricks, which deposited the material in the dam. There were two laborers to each mason employed in placing the materials, wages being 15 cts. and 35 cts. per hr. respectively. The labor cost of placing the materials was 60 cts. per cu. yd. of masonry. Mr. Parsons states that the 155,000 cu. yds. of cyclopean masonry actually cost $5.71 per cu. yd., exclusive of the plant depreciation, and that calling the plant depreciation 40% of its first cost, it would add 10% to the cost of the masonry, or 57 cts. per cu. yd., making a total of $6.28 per cu. yd. This does not include the cofferdam.

For a rubble concrete dam across the Chattahoochee, 17 miles north of Atlanta, Ga., the stone was a local gneiss that came out of the quarry in large slabs with parallel beds, some stones containing 4 cu. yds. each. About 40% of the dam was of this rubble and 60% of concrete between the rubble stones. The concrete was a 1 : 2½ : 5 mixture.

The breakwater at Marquette, Mich., was built of rubble concrete, the rubble stones amounting to 27% of the volume of the breakwater masonry.

The Hemet Dam, California, is built of granite rubble concrete, the concrete being a 1 : 3 : 6 mixture. The face stones of the dam were laid in mortar. There were 31,100 cu. yds. of masonry, which required 20,000 bbls. of cement, or 0.64 bbl. per cu. yd. The cement was hauled 23 miles over roads having grades of 18% in places, the total ascent being 3,350 ft. The cost of hauling was $1 to $1.50 per bbl. The sand was conveyed 400 ft. from the river to the dam by an endless double-rope carrier provided with V-shaped buckets spaced 20 ft. apart, the rise of the conveyor being 125 ft. in the 400 ft. This was a simple and inexpensive conveyor.

The Boonton Dam, Boonton, N. J., is of cyclopean masonry, that is, of large rubble stones bedded in concrete. The concrete was made so wet that when the stones were dropped into it the concrete flowed into every crevice. The granite rubble stones measured from 1 to 2½ cu. yds. each. The materials were all delivered on cars, from which they were delivered to the dam by derricks provided with bull-wheels. On the dam were 4 laborers and 1 mason to each derrick, and this gang dumped concrete and joggled the rubble stones into it. A derrick has laid as much as 125 cu. yds. of masonry in 10 hrs.

With 35 derricks, 20 of which were laying masonry and 15 either passing materials to the other derricks, or being moved, as much as 21,000 cu. yds. of masonry were laid in one month. The amount of cement per cubic yard of masonry was 0.68 bbl., the cyclopean stone occupying 45 to 50% of the volume of the dam.

Cost of the Boonton Dam, Cyclopean Masonry.—In the preceding paragraph the character of this masonry is given. Mr. E. L. Harrison informs me that the rock was syenitic granite, "not quite so hard to quarry as trap rock." About 50% was concrete, mixed 1:9, and 0.68 bbl. cement was required per cu. yd. of the masonry, at $1.50 per bbl. Wages of common laborers were $1.55 per 10-hr. day, and the cost to the contractor would have been $4 per cu. yd. had he furnished the cement.

Mr. J. Waldo Smith has stated that 45% of the dam was cyclopean stone and that the cost to the contractor was $3.23 per cu. yd. exclusive of cement. If we add $1.05 for cement, we have $4.28 per cu. yd.

Some English Data on Rubble Concrete.—The following is an abstract of an article from London "Engineering": Railway work, under Mr. John Strain, in Scotland and Spain, involved the building of abutments, piers and arches of rubble concrete. The concrete was made of 1 part cement to 5 parts of ballast, the ballast consisting of broken stone or slag and sand mixed in proportions determined by experiment. The materials were mixed by turning with shovels 4 times dry, then 4 times more during the addition of water through a rose nozzle. A bed of concrete 6 ins. thick was first laid, and on this a layer of rubble stones, no two stones being nearer together than 3 ins., nor nearer the forms than 3 ins. The stones were rammed and probed around with a trowel to leave no spaces. Over each layer of rubble, concrete was spread to a depth of 6 ins. The forms or molds for piers for a viaduct were simply large open boxes, the four sides of which could be taken apart. The depth of the boxes was uniform, and they were numbered from the top down, so that, knowing the height of a given pier, the proper box for the base could be selected. As each box was filled, the next one smaller in size was swung into place with a derrick. The following bridge piers for the Tharsis & Calanas Ry. were built:

Name.	Length of Bridge. Ft.	Height of Piers. Ft.	No. of Spans.	Cu. Yds. in Piers.	Weeks to Build.
Tamujoso River	435	28	12	1,737	14½
Oraque	423	31	11	1,590	15
Cascabelero	480	30 to 80	10	2,680	21
No. 16	294	28 to 50	7	1,046	16½
Tiesa	165	16 to 23	8	420	4

It is stated that the construction of some of these piers in ordinary masonry would have taken four times as long. The rock available for rubble did not yield large blocks, consequently the percentage of pure concrete in the piers was large, averaging 70%. In one case, where the stones were smaller than usual, the percentage

of concrete was 76½%. In other work the percentage has been as low as 55%, and in still other work where a rubble face work was used the percentage of concrete has been 40%.

In these piers the average quantities of materials per cubic yard of rubble concrete were:

448 lbs. (0.178 cu. yd.) cement.

0.36 cu. yd. sand.

0.68 cu. yd. broken stone (measured loose in piles).

0.30 cu. yd. rubble (measured solid).

Several railway bridge piers and abutments in Scotland are cited. In one of these, large rubble stones of irregular size and weighing 2 tons each were set inside the forms, 3 ins. away from the plank and 3 ins. from one another. The gang to each derrick was: 1 derrickman and 1 boy, 1 mason and 10 laborers, and about one-quarter of the time of 1 carpenter and his helper raising the forms. For bridges of 400 cu. yds., the progress was 12 to 15 cu. yds. per day. The forms were left in place 10 days.

To chip off a few inches from the face of a concrete abutment that was too far out, required the work of 1 quarryman 5 days per cu. yd. of solid concrete chipped off.

Concrete was used for a skew arch over the River Dochart, on the Killin Ry., Scotland. There were 5 arches, each of 30 ft. span on the square or 42 ft. on the skew, the skew being 45°. The piers were of rubble concrete. The concrete in the arch was wheeled 300 ft. on a trestle, and dumped onto the centers. It was rammed in 6-in. layers, which were laid corresponding to the courses of arch stones. As the layers approached the crown of the arch, some difficulty was experienced in keeping the surfaces perpendicular. Each arch was completed in a day.

In a paper by John W. Steven, in Proc. Inst. C. E., the following is given:

	Concrete per cu. yd.	Rubble Concrete per cu. yd.	Per Cent of Rubble in Rubble Concrete.
Ardrossan Harbor	$6.00	$5.00	20.0
Irvine Branch	7.00	3.68	63.6
Calanas & Tharsis Ry.	7.08	3.43	30.3

Cost of a Rubble Concrete Abutment.—Mr. Emmet Steece gives the cost of 278 cu. yds. rubble concrete in a bridge abutment at Burlington, Ia., as follows:

	Per cu. yd.
0.82 bbl. Saylor's Portland at $2.60	$2.14
0.22 cu. yd. sand, at $1	0.22
0.52 cu. yd. broken stone, at $0.94	0.49
0.38 cu. yd. rubble stones, at $0.63	0.24
Water	0.07
Labor (15 cts. per hr.)	1.19
Foreman	0.09
Total	$4.44

The concrete was 1 : 2½ : 4½, laid in 4-in. layers, on which were laid large rubble stones spaced about 6 ins. apart. Concrete was rammed into the spaces between the rubble, which was then covered with another 4-in. layer of concrete, and so on. A force of 28 men and a foreman averaged nearly 40 cu. yds. of rubble concrete per day. The cost of lumber for the forms is not included. The abutment was 3 ft. wide at top, 9 ft. at the base and 30 ft. high.

Cost of a Rubble Concrete Dam in the Central States.*—This article describes the earthwork and concrete construction incident to a hydro-electric development in the middle West. Although neither the name of the contractor nor the locality of the work can be given, it will serve all statistical purposes to state that the work was located within 200 miles of Chicago in a small country town, whose population was made up almost entirely of those employed on the construction, but one whose railroad facilities were all that could be desired. The river is one of the upper tributaries of the Mississippi, draining over 1,200 square miles of densely wooded forest land, flowing through a series of broad marshes and swift rapids, deep cut in the narrow valleys, until it empties into the mother stream. At the chosen site there is an average depth of 6 ft. and flow of 600 cu. ft. per second, which will impound a reservoir with an area of 650 acres and a maximum depth of 50 ft., 10 ft. of which is available, as the river here narrows down from a wide marsh plain to a deep rocky channel, making an ideal spot for water storage.

The dam is a structure of cyclopean masonry, having a spillway of 490 ft. flanked on each side by abutments of the same material and earth dikes extending 1,500 and 2,800 ft. from each end. The dam itself has a maximum height of 49 ft. and a width of base of 49 ft., its section being of a standard "ogee" type. The earth dikes have an extreme height of 31 ft., side slopes of 2 to 1, 4-ft. berms, and are made impervious by concrete core walls founded on bedrock. These have a thickness of 2 ft. at the top and a batter of 12 on 1 on each side.

The preliminary construction work, consisting of the erection of a camp for the working force of 400 men and the clearing of the dam site, was commenced April 10, but it was not until the following June that the organization was complete and the work well under way, the first concrete being laid July 9. The actual work of harnessing the river was accomplished by building above the dam location a timber rock-filled cofferdam, 500 x 150 ft., with a maximum height of 16 ft., the natural bank forming one side, thereby diverting the water into the east half of the river channel and allowing the excavation to be carried in the dry to bedrock.

Concrete mixing plants were erected on each side of the river, containing three No. 4 Ransome mixers. An excellent granite quarry was opened up on the east side of the river, where a crushing plant

---

**Engineering-Contracting*, Oct. 7 1908.

of considerable capacity was erected, the broken stone being carried from there to the bins of the mixing plants by construction trains of Western dump cars. Sand and gravel were obtained from a nearby borrow pit with drag scrapers, screened and brought to the bins in dump-car trains. Cement was kept in an adjacent storehouse and wheeled by hand to chutes immediately above the mixers.

The mixture was in 1 cu. yd. batches in the proportions of 1:2½:5, using Atlas Portland cement. About 150 cu. yds. is the average daily output of each mixer. The concrete was delivered in 1 cu. yd. tipping buckets and placed in the forms by means of push cars and 5-ton, 60-ft. boom, guyed derricks, operated by Lidgerwood and American double-drum engines, which were the limiting factors in the daily progress. Plum stones up to 1 cu. yd. in volume were bedded in the concrete and formed about 25% of its mass. Lifts of 3 to 8 ft. a day were secured, care being taken in filling the forms to complete a horizontal course over the whole surface. Successive fills were bonded together by the use of large stones imbedded so as to project half way above the surface of the lower course and lock with the subsequent layer.

The forms were built of 2-in. dressed pine planks, braced with 4 x 6-in. studding, spaced 3 ft. apart on centers and stiffened with 6 x 8-in. horizontal waling pieces attached every 4 ft. The forms were anchored with heavy iron wire, or ⅛-in. band iron, and were not interchangeable, being knocked down as each section was stripped, and rebuilt for the next.

The dam was constructed in alternate sections, 40 ft. long, bonded together with vertical keys, 3 ft. apart in the clear and terminating 2 ft. below the upper surface. Upon reaching the center, the end cofferdams were removed and rebuilt across the east channel, sending the water through five 10 x 10-ft. sluiceways left temporarily in the structure. The excavation was then pushed forward in the east channel, and on Dec. 3 the last bucket of concrete was placed in the closing sluices.

The earth dikes were filled by drag and wheel scrapers drawn by Missouri mules, the former being used for all hauls under 200 ft. The corewalls were first constructed on bedrock, the concrete being wheeled in barrows an average of 200 ft. from construction train to forms. Care was taken to bring no unnecessary stress on the walls by maintaining the fill at equal heights on each side of the core. Clay puddle and riprap protect the sides from erosion.

The plant and construction costs were as follows:

Camp.—The camp consisted of the following buildings:

	Floor Area, Sq. Ft.
8 dormitories for 283 men	15,000
2 mess halls for 80 men	3,000
3 individual shacks for 3 men	864
1 storehouse	1,136
1 machine shop	900
1 blacksmith shop	100
Total floor area	21,000

The cost of constructing these buildings was as follows:

Item.	Cost.
158,000 ft. B. M. of lumber at $22.50	$3,575
15 carpenters 48 days at $3	2,160
30,000 sq. ft. tar paper at $0.0225	675
Nails	145
Total 21,000 sq. ft. at $0.31	$6,555
Interest and depreciation	5,500

The cost per square foot of building was as follows:

	Per sq. ft.	Per cent.
Lumber	$0.17	55
Labor	0.10	32
Roofing and hardware	0.14	13
Total	$0.31	100

The carpenter work cost $13.70 per 1,000 ft. B. M., which is a high cost.

Sand and Gravel.—The excavation and screening of the sand and gravel required the following plant: One screening plant, 6 wheel scrapers, 7 spans of mules and harnesses, 6 living tents, 2 mule tents, ⅓ dinkey engine, 6 Western dump cars and ⅓ mile of track. The investment cost of the plant was $11,500; the daily plant charge was as follows for 165 days:

	Per day.
Interest and depreciation, $5,000	$30.30
Coal for boiler	2.00
Coal for ⅓ dinkey	0.50
Oil for engine	0.40
Oil for ⅓ dinkey	0.10
Feed and care of mules	7.50
Total	$40.80

Broken Stone.—The plant for quarrying and crushing the broken stone was as follows: One No. 5 Austin crusher, 1 hoisting engine and boiler, 1 60-ft. derrick, 4 steam drills, 6 scale boxes, 1,200 ft. track, ⅔ dinkey engine, 6 Western dump cars, 1 blacksmith's shop and 1 winch. The investment cost was $13,000; the daily plant charges were as follows for 170 days:

	Per day.
Interest and depreciation, $5,500	$32.30
Coal for boilers	5.50
Coal for ⅔ dinkey	1.00
Oil for engines	0.30
Oil for dinkey	0.20
Explosives	22.50
Total	$61.80

Mixing.—The mixing plant consisted of 2 mixing plants (3 No. 4 Ransome mixers, 1 cu. yd. batch), 3 cement trucks, 700 ft. of track with trestle, 2 cement houses, 1 sand chute and 2 sand cars. The investment cost of the plant was $7,900; the daily plant charges were as follows for 168 days:

Item.	Per day.
Interest and depreciation, $2,900	$17.20
Coal	2.10
Oil	0.15
Total, 180 cu. yds., at $0.10	$19.45

Placing.—The plant required for placing concrete was as follows: Six hoisting engines and boilers, 7 derricks, 9 tipping buckets, 800 ft. of track, 6 flat cars, 500 ft. of trestle, 1 dinkey, 4 Western dump cars, 15 wheelbarrows and 18 shovels. The investment cost was $18,000 and the daily plant charge was as follows:

Item.	Per day.
Interest and depreciation, $5,600	$31.75
Coal	5.00
Oil	1.00
Total, 180 cu. yds., at $0.21	$37.75

Wages.—The wages paid labor were as follows:

Class.	Per day.
Foremen	$3.00 to $5.00
Engineers	$2.25 to $3.50
Firemen	$1.75 to $2.75
Tagmen	$2.00
Carpenters	$2.00 to $3.50
Rivermen	$3.00
Electricians	$3.00
Riggers	$2.50 to $3.50
Mechanics	$2.75 to $3.50
Cooks	$2.00
Laborers	$1.75 to $2.25
Water boys	$1.50

Main Dam and Concrete.—The cost in place of the 30,000 cu. yds. of rubble concrete in the main dam inclusive of labor and plant charges was as follows:

	Foremen.	Skilled Laborers.	Laborers.	Cost Per cu. yd.
Stone	3	8	6	$1.26
Sand	1	2	10	0.46
Cement	..	..	..	2.31
Forms	3	25	1	0.62
Mixing	4	3	32	0.58
Placing	3	6	46	0.69
Total				$5.92

Referring to the forms, the cost of material per foot board measure was:

	Per ft. B. M.
Lumber	$0.022
Nails	0.001
Wire	0.005
Total	$0.028

The forms were used three times and the average cost of forms per square foot of surface covered was 24 cts., which is a very high cost.

Concrete Corewall, East Dike.—This corewall averaged 11.2 ft. in height, contained 2,893 cu. yds., and took 78 days, including Sundays and idle days, to build with a force of 5 foremen, 10 skilled laborers and 80 laborers. Sectional forms 4 x 12 ft. of 1-in. boards and 2 x 6-in. studding, were used. The concrete was delivered to trestle running 1,000 ft. by train. The cost of the corewall was as follows:

Item.	Total.
3,350 bbls. cement, at $2.31	$ 6,675
964 cu. yds. sand and gravel, at 75 cts.	725
1,928 cu. yds. broken stone, at $1.08	2,082
Mixing concrete (2,983 cu. yds., at 42 cts.)	1,215
Placing concrete (2,893 cu. yds., at $1.01)	2,947
22,400 sq. ft. forms, at 43 cts.	1,232
Total	$14,876
1,450 cu. yds. excavation, at 98 cts.	1,424
Grand total	$16,300

The cost per cubic yard of concrete work proper was thus $5.14 and the cost including excavation was $5.66 per cu. yd.

Earthwork.—The cost of the earthwork in the dikes was as follows:

East dike: Volume, 21,900 cu. yds., sandy loam; force, 2 foremen, 44 laborers, 60 mules; lead, 600 ft.; plant, No. 2 wheel scrapers; unit cost, 28 cts. per cu. yd.

West dike: 8,900 cu. yds., sandy loam; force, 1 foreman, 14 laborers, 20 mules; lead, 60 ft.; plant, drag scrapers; unit cost, 26 cts. per cu. yd.

Cost of Concrete Fence Post.—Mr. J. A. Mitchell gives the following:

Fence posts need not contain more than 0.6 cu. ft. of concrete, if the posts are made tapering. They should be reinforced with galvanized wire, for the metal is so close to the surface of the concrete that it is likely to rust. Two men will make 100 such posts per day, or 2.22 cu. yds.; while three good men have made 200 posts per day, or about 1.5 cu. yds. per man. A double mold for making two parts is used, and should be collapsible, so that it can be removed in 24 to 48 hrs. Wooden molds that have been in use three years are still in service. Such posts can be made for 11 to 12½ cts. each, which is equivalent to about $5.40 per cu. yd., prices being as follows:

Cement, per bbl.	$1.50
Gravel, per cu. yd.	0.40
Galvanized wire, per lb.	.02¾
Wages, per day	1.50

Mixtures of 1 : 3 and 1 : 4 are best.

Cost of Reinforced Concrete Telephone Poles.*—The possibilities for reinforced concrete poles in transmission line work have recently been very carefully investigated by the Richmond (Ind.) Home Telephone Co., which has constructed a line across the Whitewater River, using poles ranging from 45 to 55 ft. in height of the construction shown by Fig. 2, invented by Mr. Wm. M. Bailey, Vice-President and General Manager of the company. The following account of these investigations and of the studies made by the American Concrete Pole Co., Richmond, Ind., which has been organized to market the poles, has been compiled from information given us by Mr. Bailey.

For poles 30 ft. long and under, the molding is done horizontally

**Engineering-Contracting,* March 11, 1908.

on the ground and the pole erected when hard like a wooden pole; for poles over 30 ft. long the molding is done in forms set vertical in the pole hole. The following figures, Table IX, are given as the cost without royalty of concrete poles molded as described. These costs are for poles erected excluding the material cost of steps but in-

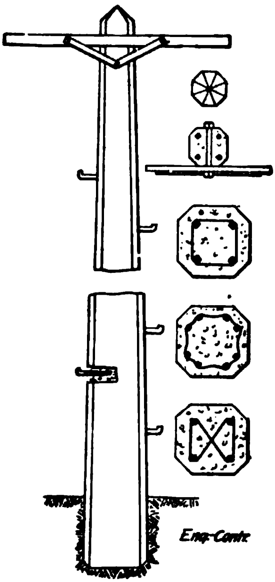


Fig. 2.—Concrete Telephone Pole.

cluding labor cost of setting steps, and they are based on the following wages and prices:

Foreman, per day	$3.00
Laborers, per day	1.75
Cement, per barrel	2.00
Stone, gravel or sand, per cu. yd.	1.00

For sake of comparison, the cost of cedar poles has been added to the table; these costs include poles, unloading, dressing, gaining, roofing, boring, hauling and setting. All figures are as furnished by Mr. Bailey. Regarding the methods of constructing concrete poles, Mr. Bailey says:

"All of the larger concrete poles (that is, poles over 30 ft. in height), are built upright in position ready for use, the forms being set perpendicularly over the hole in which the pole is to be placed, the hole having been dug to conform with the size pole prior to the setting of form; thus when the concrete is poured in at the top of form, the hole is entirely filled and the concrete knit firmly to the

TABLE IX.—COMPARATIVE COST OF REINFORCED CONCRETE AND CEDAR POLES.

	Concrete Poles.									Cedar Poles.			
											Cost.		
Lgth., ft.	Top, ins.	Bottom, ins.	Size Steel, ins.	Cu. ft. conc.	Cost of steel.	Cost of concrete.	Cost of bind., W.	Labor.	Total cost.	Top, ins.	F. o. b. cars.	Labor.	Total.
25	6	10	¼	16	$1.57½	$2.24	$1.20	$1.70	$6.71½	7	$2.60	$1.50	$4.10
30	6	11	⅜	21	2.29	2.94	1.20	2.20	8.63	7	6.25	2.00	8.25
35	6	12	½	26	3.91½	3.64	1.20	2.70	11.45½	7	8.75	2.40	11.15
40	7	15	⅝	36	6.31	5.04	1.50	4.20	17.05	8	12.00	3.50	15.50
45	7	16	⅞	43	8.56	6.02	1.50	5.70	21.78	8	17.20	5.00	22.20
50	7	17	⅞	50	9.50	7.00	1.80	7.20	25.50	8	20.20	6.50	26.70
55	7	18	1	56	13.34	7.84	1.80	8.95	31.93	8	24.80	8.50	33.30
60	7	19	1	61	14.56	8.54	1.80	11.70	36.60	8	29.75	10.00	39.75

solid earth that has never been disturbed. There is no replacing of earth or tamping required.

"All poles under 30 ft. in height, up to the present time, have been built on the ground and set after they have been seasoned, although there is some doubt in my mind and I believe that with the proper equipment and a little practice that it will be discovered that even the smaller poles can be built more economically upright. As to the cost of setting these poles, it is true that they will have to be handled with a derrick or gin pole, but with this equipment they can be handled very rapidly, and, I believe, almost as cheaply as the wooden pole. One can readily see that as the larger poles are built upright in position which they are to occupy, that there is no heavy material to handle—consequently, there will be no necessity for any heavy rigging or equipment. The hole is first dug and the form is set directly over the same. After the form has been placed, the reinforcing rods and binding wires are placed and the form is then ready to receive concrete. After the concrete has been poured in, it is left for about three or four days, depending on the weather, before the forms are removed. The most economical way of handling concrete is with a small mixer, capable of mixing 2 or 3 cu. yds. per hour and the old-fashioned grain elevator. With this equipment, the concrete is placed as rapidly as it is mixed and with the same power. The pouring in of the concrete into the top of the form tamps it thoroughly and it shows a solid compact concrete.

"This proposition is like a great many others—at first sight it appears impractical on account of first cost, but on investigation we find that this is only a phantom and that after all is done and said, the proposition is economy.

"I give you here the exact cost data on one of the 55-ft. poles erected over the Whitewater river at Richmond, Ind.:

Materials:	
4 1-in. steel rods 40 ft. long, and 4 ¾-in. steel rods, 15 ft. long including "U" bolts with which they were tied together	$13.34
56 cu. ft. of concrete	7.84
1 set of binding wires	1.80
Total materials	$22.98
Labor:	
4 men setting form, placing rods, and binding wire, guying, truing same ready for concrete, one day:	
1 man, at $3.00	$ 3.00
1 man, at $2.50	2.50
2 men, at $2.00	4.00
4 men and one horse mixing and placing concrete, 2 hrs. and 11 mins.	2.28
2 men taking down form and touching up pole, 3 hrs.	1.35
Total labor	$13.13
Total materials and labor	$36.11

"You will note that this cost is $4.18 in excess of my tabulated statement (Table I). This was due to the location of the lead.

These poles were set in over rough ground and in a river bottom where we had water to contend with and the conditions were very unfavorable to the erection of any kind of poles. It would have cost considerable more to set wood poles in the same place. We were also obliged to use labor inexperienced on this class of work. I believe that after the men are properly broken in and equipment working properly, that concrete poles can actually be built for less than first-class cedar complete, set in the ground. There is no comparison between wood and concrete when we take into consideration strength, durability, and its lack of destruction from other causes, such as birds, insects, lightning, etc. The more thought and test that the writer applies to this method of construction, the more enthusiastic he has become and he expects to see the day when no first-class construction will consider anything but steel, iron or concrete poles."

Cost of Reinforced Concrete Poles.*—Mr. F. J. Hunt is author of the following:

The prime factors in the construction of concrete poles are the materials forming the grout. This is true of all concrete construction, but particularly so in the construction of concrete poles, where the cross-section is small and the greatest possible tensile strength is desired. Unless the best quality of crushed stone and sand is used, desired results cannot be obtained. Fig. 3 shows the method of molding concrete poles on which these and the following remarks are based.

The steel reinforcing rods are placed 1 in. from the surface of the pole in 3 sets; four rods extend to the top of the pole, four rods two-thirds of the length of the pole and four rods one-third of the length. In testing the finished pole to destruction this distribution of the steel was found to be practical, giving a uniform stress from top to ground line. A 30-ft. pole with 6-in. top and 9-in. base deflected 3 ft. at the top from a plumb line, and straightened when the load was removed without any apparent damage to the pole. A 30-ft. pole must stand a strain of 2,500 ft. lbs., at the groundline. The feature to be reckoned with in the building of a line of concrete poles is the transportation and erection. A 30-ft. pole, with a 6-in. top, will weigh 2,000 lbs. It is a practical proposition to build this length pole in a yard, in forms on the ground. A pole of any greater length should be built in place, from the ground up, although I have erected 45-ft. poles that weighed 5,600 lbs. The 30-ft. reinforced concrete pole can be built in Chicago for $7.50 and erected with proper equipment for $1 each.

The reinforced 30-ft. concrete pole with 6-in. top and 10-in. base, and corners chamfered to 1-in. radii contains ½ cu. yd. of concrete and 200 lbs. of steel, the cost being as follows:

200 lbs. of steel, at $1.85 per 100 lbs.	$3.70
½ cu. yd. concrete, at $7.50 per yd.	3.75
Total	$7.45

*Engineering-Contracting, Feb. 26, 1908.

The estimate of the cost of the finished pole is based on the following prices: Crushed stone, $1.25 per cu. yd.; sand, $1.10 per cu. yd.; cement, $1.75 per bbl., and labor, 20 cts. per hr. In erecting concrete poles, the equipment will vary to suit the conditions. On traction lines, where the poles are close to the track, the most convenient method of erection is to rig a hinged stiff-leg derrick on a flat car, with a boom of sufficient length to pick up poles on cars at

Fig. 3.—Molding Poles.

either end of the derrick car. This derrick should be hinged so as to be conveniently lowered to pass under grade-crossings and obstructions of any nature. On steam railway construction, where the pole line is often 60 to 70 ft. from the track, a derrick truck with jack-arms is used in the same manner as the car, picking up the delivered poles from the ground instead of from the car.

Bills of Materials and Cost of Concrete Poles.*—The increasing cost of wooden poles for telephone, telegraph, trolley line and other electric transmission line work is leading engineers seriously to search for some substitute material. This material is believed by a number of engineers to be reinforced concrete and within the last year or two there have been quite extensive studies of reinforced concrete pole construction. The results of some of these studies are given in the succeeding sections, and in connection with them the reader will do well to consult the article published in our issue of Nov. 20, 1907, describing the construction of 150-ft. transmission line

---

**Engineering-Contracting*, Jan. 29, 1908.

poles for the Lincoln Light & Power Co. in Ontario and giving the methods adopted for computing the stresses.

Comparative Strength Tests of Concrete and Cedar Poles.—In 1906 two forms of reinforced concrete poles were tested in comparison with two 30-ft. selected cedar poles for Mr. G. A. Cellar, Superintendent of Telegraph, Pennsylvania Lines west of Pittsburg. The concrete poles were made and the tests conducted by Mr. Robert A. Cummings of Pittsburg, Pa. Both poles were 8 ins. in diameter at the top and 13 ins. in diameter at the base and both poles were molded hollow, with shells from 1¾ ins. to 3 ins. thick, for about two-thirds of their height and solid for the rest of the height. One pole was octagonal in section and one was square in section with chamfered corners. Each pole weighed approximately 3,500 lbs. Both poles were designed to carry 50 wires each coated with ice enough to make it 1 in. in diameter, and to resist a wind load of 30 lbs. per sq. ft. The poles were assumed to stand 100 ft. apart and were made 30 ft. high. These conditions are approximately equivalent to a concentrated load of 1,000 lbs. applied near the top of the pole. The reinforcement for both poles consisted of a peripheral ring of eight 24-ft. bars of round steel and alternately ¾ in. and ⅝ in. in diameter. Wooden blocks were molded into the poles for attaching clips and braces and through holes cored for cross-arm bolts. Both the wooden and the concrete poles were set approximately 5 ft. into 3 x 3 x 5 ft. concrete bases.

Mr. Cummings describes the method of conducting the tests as follows:

"The load was applied through a band 10 ins. from the top of the pole by means of two ¾-in. wire ropes which passed over two 12-in. sheaves near the end of an inclined A-frame. These ropes received the hook supporting a differential chain hoist of 5 tons capacity. The base of the A-frame rested freely upon the front edge of the concrete foundation and inclined away from the poles at an angle of 45°. A pulley suspended from the extreme end of the A-frame carried the differential hoist, the lever arm and counterweight. The initial load applied at the top of the pole was thus reduced to 50 lbs. The total amount of applied load was measured by a simple lever. One end of which was supported on the platform of a 2,500-lb. capacity weighing scale, while the other end was attached to chain hoist. The two acted through a rocker fulcrum suitably supported. The load was applied or released by operating the differential hoist. In applying the load the hoist would reduce the distance between the hooks at any rate of speed desired. A graduated rule was fastened at the top of the pole being tested and extended back parallel with the line of poles crossing the arm containing a gage pin, from which point deflections were read. This arm was nailed to a rigidly braced upright erected near the rear telegraph pole. Deflections (Table X) were also read 12 ins. above the foundations by means of a movable rule. The platform for supporting the observer reading deflections at top of poles was suspended from a nearby bridge. The accompanying table gives the loads and corresponding deflections of four poles

tested. The white cedar poles broke about 7 ft. above the foundation. The concrete poles failed by crushing of the concrete in the base of poles at the level of the foundation."

TABLE X.—LOADS AND DEFLECTIONS FOR FOUR POLES TESTED.

Test No.	Deflection at top, ins.	Load, lbs.	Deflection at bottom, ins.	Time.	Remarks.
		Octagonal Concrete Pole.			
1	3¾	1,830	1/32	3:17	
	5¾	2,230	1/16	3:18	
	½	50	1/32	....	Temp. deflec.—½ in.
2	8	2,630	⅛	3:19	
	11¾	3,030	3/16	3:20	Crks. Nos. 1 and 2.
	1¼	50	1/16	....	Temp. deflec.—2 in.
3	14¼	3,430	¼	3:24	Cracks Nos. 3 and 4.
	18	3,210	⅜	3:25	Crk. 5 crshd. at bot.
	25½	3,150	¾	3:26	Pole brk. at grnd. lev.
		Square Concrete Poles.			
	¼	50	..	2:02	
1	2½	1,830	..	2:04	
	3½	2,230	..	2:08	
	¾	50	..	....	Temp. deflec.—1 in.
2	4 9/16	2,630	..	2:10	
	8½	3,030	1/16	2:11	
	3½	50	..	....	
3	31	3,290	..	....	
	34½	3,430	⅛	2:14	Crk. No. 1.
	21¼	50	..	....	Temp. deflec.—22 ins.
4					Crks. 2, 3, 4, pl. crshd.
	39	3,690	..	2:19	Crkd. at grnd. lev.
		Wooden Pole No. 1.			
	20	1,830	..	11:50	
	22¼	2,230	..	11:51	
	29	2,630	..	11:52	
	35	2,870	..	11:53	First crack.
1	36½	2,950	..	11:54	
	38½	3,030	..	11:55	
	50	3,370	..	11:56	
	56	3,430	..	11:57	
	66	3,494	..	12:00	Pole brk. suddenly.
		Wooden Pole No. 2.			
	14	172	..	....	
1	37	2,230	..	....	
	47	2,530	..	11:03	Pole brk. suddenly.

Nashville, Chattanooga & St. Louis Ry.—Fig. 4 shows the standard reinforced concrete pole designed to support bridge warnings by Mr. Hunter McDonald, Chief Engineer, Nashville, Chattanooga & St. Louis Ry. Originally the pole was molded with pole, cross-arm and brace all of concrete and in one piece, but this was found too expensive and the gas pipe cross-arm and brace were substituted. One pole of each construction has been in use over three years. The one with the concrete cross-arm shows considerable bending, but the other does not. The bill of materials for the concrete pole shown by Fig. 4 is as follows:

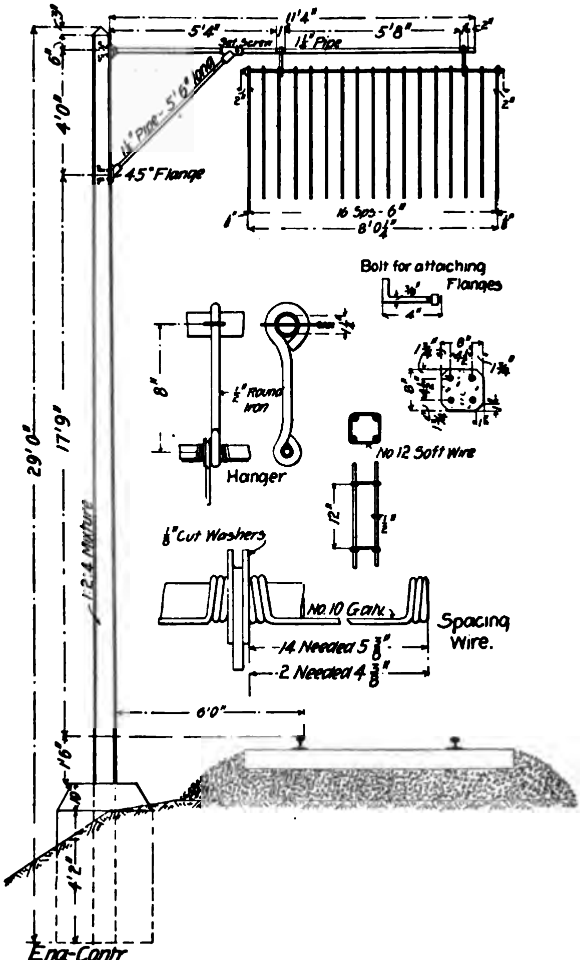

11'4"
5'4"
5'8"
1½" Pipe
Set Screw
1½" Pipe - 5'6" long
45° Flange
16 Sps - 6"
8'0½"
Bolt for attaching Flanges
Hanger
½" Round Iron
No 12 Soft Wire
½" Cut Washers
No. 10 Galv.
Spacing wire.
14 Needed 5⅜"
2 Needed 4⅜"
6'0"
29'0"
17'9"
4'0"
1:2:4 Mixture
4'2"
Eng-Contr

Fig. 4.

Shaft: ½ cu. yd., platform screenings, ¼ cu. yd. sand, and 2½ bags Portland cement.

Base: 1½ cu. yds. crushed stone, ¾ cu. yd. sand, and 6 bags Portland cement.

Fort Wayne & Wabash Valley Traction Co.—This company operating some 150 miles of street and interurban trolley line proposes to make its renewals with concrete poles of the construction shown by Figs. 5 to 8. Fig. 5 shows the 42-ft. pole complete and Figs. 6, 7 and 8 show, respectively, the 32 and 30-ft. pole reinforcement. The weight and dimensions of the pole and the bill of material required are given for each size. Regarding the construction of these poles Mr. H. L. Weber, Chief Engineer of the road, writes:

"The cost of constructing concrete poles depends so much upon the location of the materials with respect to the points where the poles are to be erected that general figures are difficult to state. Having several good gravel banks at convenient points along our right of way, which is 120 miles in length, and having our road already built and the equipment available for handling materials and poles, we have been able to build concrete poles for about the same cost as a wooden pole all fitted up and painted. We figure that a 33-ft. pole costs $7.50 and a 45-ft. pole costs $15, at pit. It is difficult to figure the cost of molds, as one mold should be good for a number of poles, depending on the care that is taken of it.

BILL OF MATERIAL, FIG. 5.

Item.	Lbs.
4 pcs. ¾-in. x 42 ft. twisted steel bar	321.2
8 pcs. ½-in. x 32 ft. twisted steel bar	217.6
8 pcs. ⅜-in. x 16 ft. twisted steel bar	61.2
20 pcs., total weight of steel	600.0
Concrete, 237 cu. ft., weight	3,030.0
Approximate weight of pole	3,630.0
Surface area of steel	14,176 sq. in.
Base area of steel	5,375 sq. in.

BILL OF MATERIAL, FIG. 6.

Item.	Lbs.
12 pcs. ⅝-in. x 30-ft. twisted steel bar	172.0
8 pcs. ⅜-in. x 20 ft. twisted steel bar	76.6
8 pcs. ⅜-in. x 10 ft. twisted steel bar	38.3
28 pcs., total weight of steel	286.9
Concrete, 13.7 cu. ft.	1,758.0
Approximate weight of pole	2,044.9
Surface area of steel	10,800.0 sq. in.
Base area of steel	3.93 sq. in.

BILL OF MATERIAL, FIG. 7.

Item.	Lbs.
4 pcs. ½-in. x 30-ft. twisted steel bar	102.0
12 pcs. ⅜-in. x 20 ft. twisted steel bar	114.7
8 pcs. ⅜-in. x 10-ft. twisted steel bar	38.3
24 pcs., total weight of steel	255.0
Concrete, 13.7 cu. ft., weight	1,758.0
Approximate weight of pole	2,013.0
Surface area of steel	10,560 sq. in.
Base area of steel	3,812 sq. in.

No records of cost were kept.

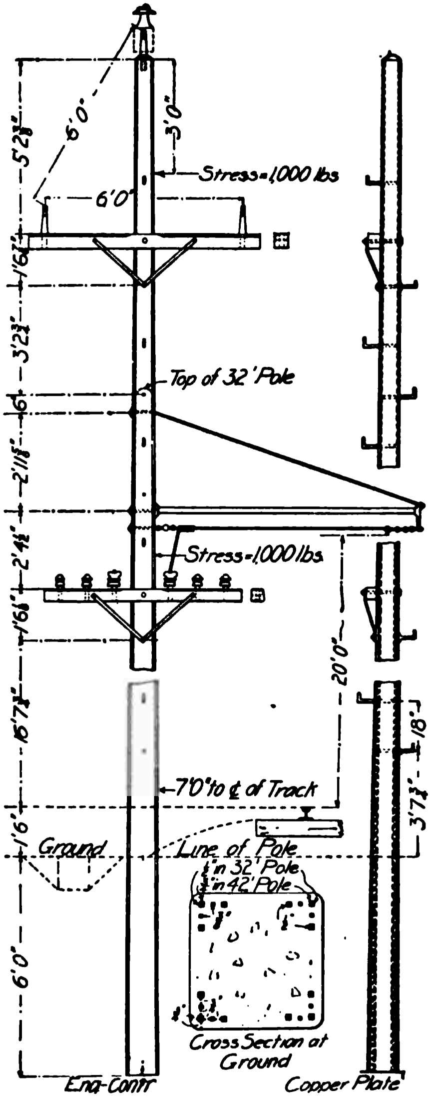


Fig. 5.—Concrete Trolley Pole.

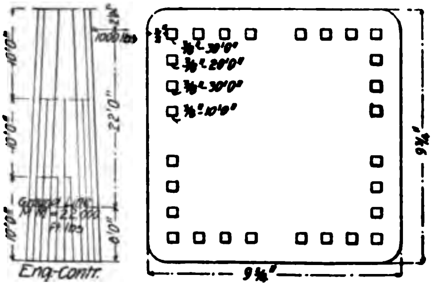


Fig. 6.

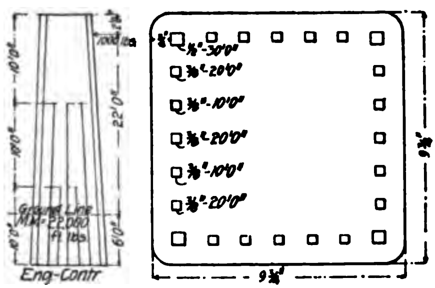


Fig. 7.

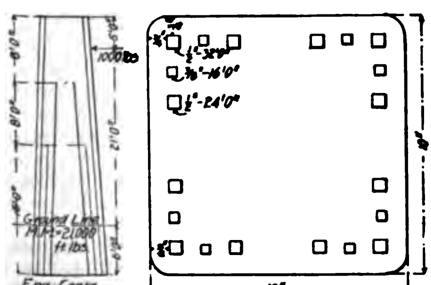


Fig. 8.

BILL OF MATERIAL, FIG. 8.

Item.	Lbs.
4 pcs. ½-in. x 32-ft. twisted steel bar.........	108.8
8 pcs. ½-in. x 24-ft. twisted steel bar.........	163.2
8 pcs. ⅜-in. x 16-ft. twisted steel bar.........	61.2
20 pcs., total weight of steel..................	333.2
Concrete, 15.1 cu. ft...........................	1,960.0
Approximate weight pole.........................	2,293.2
Surface area steel..............................	9,546 sq. in.
Base area steel	4.125 sq. in.

Pittsburg, Ft. Wayne & Chicago Ry.—In 1906 this company erected 53 poles for a mile of telegraph line near Maples, Ind. The general construction of these poles is shown by Fig. 9. They ranged in height from 25 to 34 ft. The 25-ft. pole shown by Fig. 9 was 8 ins. square at the butt and 6 ins. square at the top, the corners being chamfered to a face 2 ins. wide, so that above ground the pole was octagonal. The poles were set 4 ft. into the ground, and packed around with stone screenings. Some of the poles were erected within five days after molding.

Marshall Concrete Pole.—The following is a description of a test pole mode by Mr. Wallace Marshall, Lafayette Engineering Co., Lafayette, Ind.

"In November, 1905, I made a box form of three sides, having the top open, for a test pole. It was 35 ft. long. The lower 5 ft. was 10 ins. square; commencing at that point it tapered on all sides to 5 ins. at the top. From the 5-ft. point I put a triangular piece in each corner of the form of about 1½ ins. wide at the bottom and 1 in. at the top to chamfer the corners of the pole. At proper places of a standard linc pole for line bracket, cross-arms and telephone box I bored holes through the forms, put machine bolts through it and let them extend about 2 ins. in the forms, screwing the nuts the full length of thread. In the top of the form, which was brought to a round point, I placed a 1½-in. pin in the center to leave a hole or an insulator pin. I then filled the form with concrete mixed by hand consisting of 1 part of cement to 6 parts ordinary gravel, except a facing of about ½ in. of cement and sand 1 to 3. After covering the bottom of the form about 1½ ins. I laid in the large end two ¾-in Thatcher bars 25 ft. long, and in the top part two ½-in. Thatcher bars, lapping them about 4 ft. I left them in the form six days. At the expiration of 30 days we tested it as follows: We planted it firmly in the ground 5 ft. deep. At 25 ft. distance we planted a large cedar telephone pole. At the level of 21 ft. from the ground we fastened a wire cable from one pole to the other, which is about the height of a trolley wire. In the center of this cable we suspended a barrel. Into this barrel we loaded steel rivets gradually and watched results. The two poles began to bend as the load was applied. When the two were deflected about 21 ins. each toward the other I observed a small check come in the concrete pole about 10 ft. from the ground, and simultaneously checks appeared from the cable to the ground. We immediately stopped loading, took off the ballast, weighted it and calculated the horizontal strain and found it to be 975 lbs. The maximum moment would be at the ground,

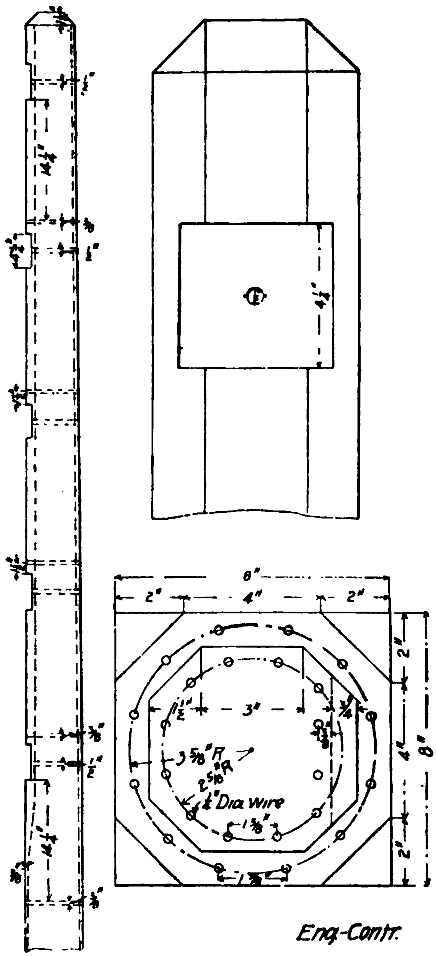


Fig. 9.—Concrete Telegraph Pole.

but the guess at size we made was about right, since the concrete cracked from ground to cable at almost the same time. When the load was removed the pole resumed its plumb position and remains so to-day, although being used for heavy guy wires. The bolts were unscrewed before moving them, leaving the nuts imbedded in the pole. After concrete set we screwed the bolts into the nuts and could not loosen them with an ordinary wrench. It took several heavy blows with a sledge hammer to break out the top socket. My conclusions were, however, that a wire ring or two of reinforcement should be placed about the pin for safety. Careful estimates were made as to costs of such a pole 35 ft. long if made in quantities in proper forms with material at the then market price, and gravel in pit at $7 actual cost. Comparing that cost with present price of pine poles and add to the latter the cost of trimming, chamfering, framing and painting, the concrete pole can be made for less money than the wood, provided no profit is paid a contractor. Figuring the moments on the pole tested I found the concrete failed at just about the time the limit of elasticity of the steel was reached, providing that it would be of no value without the steel. I believe that the concrete pole is practicable, and the only reason I have not put it to practical use has been the lack of time to do so."

Cost of Reinforced Concrete Piles for a Building Foundation.—In *Engineering-Contracting*, Mar. 24, 1909, a paper by Sanford E. Thompson and Benjamin Fox is published, of which the following is an abstract.

Arrange molding platform if possible so that butts of pile are placed to be drawn direct by pile driver.

Design butt so that pipe connection does not interfere with snatch ring. Place pipe connection so that hose can be connected before raising pile and supporting rope will not interfere with derrick hook.

If piles are made in cool weather and are to be driven in 30 days, strengthen concrete mix at butt by working some dry cement into it while ramming.

Use perfect rolls under driver to facilitate quick moving. The plan found best at Cambridge with the 4,700-lb. hammer was to begin driving by churning and water jet, using this method as long as possible. The chain connecting pile to hammer was then disconnected and driving began with hammer drop of about 2½ ft., increasing drop as driving became harder; 4 ft. may sometimes be used at the start.

In ground not too hard it may be advisable after completing churning to give the chain a slack for a ½-ft. drop, and raise pile a little with a jerk after each blow. This appears to be effective only in ground soft enough so that the pile can be readily raised, and as it takes time to adjust chain, is hard on engine, and tends to start head crushing, it is of very doubtful value.

As tip of pile should have good bearing on ground undisturbed

by water jet, the water should be shut off before the pile is down to grade.

The 8x8-in. tip was found to be slightly preferable to the 10x10-in. tip in time of driving. The 2-in. jetting pipe gave the best results, and it is suggested for future use that this be reduced to 1 in. or 1¼ ins. for the last 12 or 18 ins. at the tip.

For piles of 30 ft. or less length the longitudinal reinforcement may be ¾-in. rods instead of ⅞-in., but for piles of over 30 ft. computations should be made so that the longitudinal reinforcement will be strong enough to stand the vibrating weight of the pile when it is being raised to the gins of the machine.

Design.—The piles as designed by Mr. Fox were made 30 ft. 6 ins. long, 14 ins. square at the butt end, and in general 9 ins. square at the tip. A number of soundings were taken at the site of the power house which indicated a fill of from 6 to 8 ft.; below this to a depth of 29 ft. 7 ins. to 31½ ft. from the surface, fine sand and mud (practically all may be considered sand); and below the sand a clay hard pan was reached which was tested to a depth of 13 ft. These tests, together with a consideration of the requirements, determined the length of the pile.

Of the 48 piles which were made, 6 were 8 ins. square and 6 were 10 ins. square instead of 9 ins. at the tip. The object of this variation in size of the tip was to determine which size gave the best results. The irregularity of water pressure proved a very great handicap to making accurate comparisons and also affected very seriously the results obtained during the actual driving of each pile. Enough piles were observed, however, to give fairly good averages.

Averages of the time of actual driving the piles with different sized tips give the following results, which indicate that the 8-in. tip is slightly preferable in time of driving. The variation in the character of the ground as well as the water pressure may influence in a measure the relative times.

TIME DRIVING PILES WITH DIFFERENT SIZED TIPS.

Size of Tip. Ins.	Range in Time Driving. Mins.	Average Time Driving. Mins.
8	26 to 107	66
9	22 to 166	76
10	40 to 130	85

Piles were reinforced with four ⅞-in. corrugated steel rods extending to within 2 ins. of the ends of the pile, and imbedded 2 ins. from the face near the butt and 1½ ins. from the face at the tip. Loops of ¼-in. corrugated bars were placed around the principal steel, spaced about 12 ins. apart except near the butt, where the spacing was decreased to 4 ins., there being 34 loops in all. The butts of the piles were also extra reinforced, some with ⅝-in. and some with ½-in. rods, varying in length from 2 to 3 ft. A ⅞-in. rod about 5 ft. long was imbedded in the concrete with a loop sticking out through the concrete near the top of the pile on one side for hooking with derrick.

A galvanized iron pipe was cast in the center of the pile for the water jet. For experimental purpose the sizes of pipes were varied, being 2 ins., 1½ ins., 1¼ ins. and 1 in. To carry out the experiment still further some of the piles were made with one of the larger size pipes for about half the length of the pile and there connected with one of the smaller pipes which extended down to the tip.

The times of driving piles with different sizes of pipe in the interior of the pile were plotted, but the variation in each due to other causes was so great that no practical conclusion could be reached. The results simply indicate that the pile with 1-in. pipe took slightly longer to drive than the piles with larger sized pipe.

The friction of water running through pipe of small size is very great, so that it is known without experimenting that the largest size of pipe which it is practicable to insert in a pile will give the least loss of head and therefore be the best. To increase the velocity of the water, and thus increase its power to loosen earth (note that it is the velocity, not the pressure, which is increased), the size of the tube should be reduced near the tip. The reduction must be made far enough from the tip of the pile to prevent clogging under heavy blows. There is no danger of the nozzle filling while the water is flowing freely, and therefore no danger while the pile is being churned down in the first few blows. The danger is apt to occur when the driving becomes hard, and at this time the penetration per blow is so small that it would seem that a nozzle 12 ins. long would be sufficient to prevent any material working up into the larger pipe. A 2-in. pipe is probably as large as is practicable, and it is therefore suggested that this size be used to within 12 ins., or if preferred, 24 ins. from the tip, and there reduced to 1 in.

Methods Employed in Making Piles.—The method of construction is as follows: A 2-in. platform of rough plank is built on ground of sufficient area to hold all of the piles. On this platform chalk lines are struck and V strips to form a 1-in. chamfer nailed so that the lines of the piles are about 6 ins. apart, alternating points and butts. The casting of the piles with tips and butts alternating is economical of space, but where the piles are cast so as to be handled directly by the pile driver, without any intermediate handling, it is best to cast them all with the butts toward the machine on account of the saving of time in getting the pile in the gins. Two 8-in. unplaned (to assist in skin friction) spruce planks form the sides of each pile. The piles are made in lots of about five. The outside form is cleated with 2x4's, and the other sides have the plank simply set on edge with pairs of wedges between them. There are seven cleats or wedges in the length, and seven pieces 2x4 nailed across the top of each. After setting the plank sides, beveled pieces are nailed to locate the upper surface and form a chamfer.

Steel is wired together on a table consisting of plank on three horses. The reinforcement when made is suspended in form by two wires attached to each of the 2x4 cross pieces.

Two days were usually allowed before striking the forms.

GANG MAKING PILES.

One foreman	
2 laborers on miscellaneous work, at	$0.25
4 laborers wheeling and mixing concrete, at	0.25
2 laborers ramming, at	0.25
4 carpenters, at	0.43¾
4 steel men (2 carpenters and 2 laborers), averaging	0.40

The concrete gank mixed and placed concrete in 10 piles in 10 hours. It took 4 carpenters 3¾ hours each, or a total time of 15 hours, to set up sides for 5 piles (10 sides), and 4 carpenters ½ hour each, or a total of 2 hours, to take down the sides for 5 piles. It took one carpenter and one laborer 10 hours each to wire up 5 reinforcing frames and place them in form ready for concreting.

Each frame was composed of four ⅞-in. rods in corners running full length of pile, ¼-in. hoops 12 ins. on centers except for 2 ft. at the top, where hoops were spaced 4 ins. on centers. Four additional ½-in. rods 2 ft. long and a ⅞-in. bent rod for hooking the pile were placed at this same end. A 1½-in. pipe was also placed in the center of the pile.

The concrete was mixed by hand in the proportion of 1-2-4, using ¾-in. trap rock, the sand and cement being first made into a mortar and the stone added. A thorough mix is of course essential. Mixing was started in March, precautions being taken at night against possible frost and the piles wet down every day for two weeks.

The age of the piles when driven ranged from 30 to 41 days, the larger part of them being nearer the shorter age, the average being 33½ days. The first pile was molded on March 24 and driven on April 24, and during this period the temperature was low, averaging between 40° and 50° F., so that the piles had not attained nearly their full strength. After the driving was commenced the weather became much warmer, and the piles after the first few were noticeably harder and entirely satisfactory, even although the age was practically the same, that is, about one month. The first pile driven lost its water pressure when about 6 ft. below the surface, and during the process of driving, which reached 700 blows, it is probable that it broke when about half-way down. The head of this pile was badly crushed, whereas subsequent piles which had hardened more thoroughly because of the higher temperature were uninjured, even with a similar number of blows and higher drops of the hammer.

It may be said, therefore, that a period of one month for seasoning piles is sufficient during, say, the months between May 1 and October 1, but during the colder months a longer period should be allowed unless artificial heat can be used to hasten hardening.

Pile Driver and Hammer.—It was decided, after a careful investigation of records of concrete pile driving both in this country and Europe, to use a 4,700-lb. hammer. With a view to the use of the heavy hammer and the side strains brought to bear on the

machine by the dragging of the piles from the casting platform, a special driver was built. The driver was made as follows:

Long leaf hard pine was used throughout. The bed timbers were 8x10 ins., 18 ft. in length, the gins 8x8 ins., 42 ft. long. The braces of 8x8 ins. timber were run from the bed timbers to the head of the machine with intermediate braces and ties to give the necessary rigidity. The sheave was of extra heavy pattern and the whole framework was bolted up and tied together with rods. The cushion head, which was perhaps the most essential item, as it was desired to avoid fracture of the pile from the blows of the 4,700-lb. hammer, consisted of a plate iron collar 16 ins. square on the inside and 3 ft. in height, which incased an oak block 16x16x18 ins. on to the bottom of which six thicknesses of rope and four layers of rubber belting were nailed. The cushion head was held in place in the gins of the machine by four perpendicular pieces of oak on the outside of the collar and bolted through the incased oak block. A 25-hp. Lambert engine was used and a single block for hoisting and churning the piles.

The water for jetting was furnished through a 2½-in. Bay State hose, using a compound piston pump having 7x12-in. high pressure, and 12x12-in. low pressure cylinders, and a capacity of 100 gallons per minute. This was the most unsatisfactory part of the entire work, the water pressure being invariable and uncertain and 125 lbs. the limit of pressure obtainable at the pump.

Driving Piles.—The usual process of driving consisted, after moving the pile driver, in hooking and dragging the pile and lifting it to place and attaching the hose, or attaching the hose first and then hoisting.

As already shown the casting of the piles with tips and butts alternating is economical of space, but where the piles are cast so as to be handled directly by the pile driver, without any intermediate handling, it is best to cast them all with the butts toward the machine on account of the saving of time in getting the pile into the gins of the machine. When the pile is cast with the butt end toward the machine the pile can be lifted directly into the gins, while, when the pile is cast with the tip end towards the machine, it must be chained and dragged in front of the machine before it can be hooked in the usual manner and lifted to place.

Care must be taken when making the pile to place the hook for hoisting in relation to the projecting nozzle for jetting so that the hoisting rope will not foul the hose when the pile is being raised into position. To facilitate setting the pile into the gins, a crutch of 1-in. iron was made with a 12x12-in. square key at one end with a long handle to replace the peevy or cant dog ordinarily used for wood piles. As soon as the hose was attached and the pipe in place, the water was turned on and the pile usually penetrated for a short distance without the hammer. The hammer was then placed on the cushion and the pile sank further to a depth depending upon the nature of the fill. Next the hammer was attached to the pile with a chain and the churning commenced. There was enough play

in the chain connection between the hammer and the pile to give about a 10-in. blow of the hammer each time the pile was lifted. When this churning became ineffective, the chain was disengaged and the pile was driven with blows in the usual manner.

GANG ON PILE DRIVING.

1 foreman, at $0.50 per hr.	$ 4.00
1 engineman, at $0.50 per hr.	4.00
1 pump man, at $0.25	2.00
7 men, at $2.50 per 8 hrs.	17.50
Total gang per 8 hrs.	$27.50

In addition to this gang 2 carpenters were called in occasionally for repairs, and 2 other laborers were busy most of the time in connection with cutting off piles, digging holes and odd work.

Gross Times Driving.—For convenient reference gross times driving piles are tabulated in Table I (not reproduced here) together with some of the more important details. The times, for example, are separated into "Moving Driver," "Placing Pile," "Driving" and "Delays;" and the "Number of Blows," the "Range in Drop" of hammer, and the drop and penetration under "Last Blow" are also given.

The total average time per pile is 2 hrs. and 15 mins., of which 29 mins. is moving driver, 23 mins. placing pile and 83 mins. driving (not including 27 mins. delays from various causes). This corresponds to an average of 3½ piles per 8 hrs., which agrees with the time that can be figured directly from the beginning to end of the job. As the men became more expert in moving the driver and placing the piles, it was possible to reduce the time to 1½ hrs., as shown by the average during the last four days. Even this includes about one-half hour moving pile driver, which was unnecessarily long because of imperfect rolls.

The time driving was greatly increased by the poor water pressure. Taking an average of 16 piles whose time was less than 60 mins. and which, therefore, might be assumed to have gone down fairly well, the time during the driving was 44 mins., thus giving a total of 1 hr. and 24 mins. per pile, or 5.75 piles per day instead of 3.5 piles per day.

It therefore may be assumed on another job of similar character that an average of at least 5¾ piles may be driven per day. By using perfect rolls, molding piles with butts toward pile driver, and using good water pressure, this number may be still further increased. From a study of the individual items, times may be selected and estimates made which will apply to other locations and other conditions.

Each pile received an average of 589 blows.

Instances of Hard Driving.—One of the first piles that was driven probably struck a large bowlder at 18 ft. below the surface. The pile was given 735 blows, using drops of the hammer of from 18 to 30 in. At this stage the head was so badly crushed that the driving was stopped and the projecting portion of the pile cut off. To see what effect this tremendous pounding with a 4,700-lb. hammer

had on the pile, after squaring off the crushed head it was sent to the Watertown Arsenal to be tested. The Arsenal report was as follows:

TESTS BY COMPRESSION, CONCRETE PILE NO. 13,822.

Length, 9 ft. 3 ins.
Size of butt, 12.9 ins. by 13.75 ins.
Size of tip, 11.15 ins. by 11.75 ins.
Weight, 1,458 lbs.
Cross-sectional area (smaller end), 128.59 sq. ins.
Ultimate strength, 497,000 lbs. = 3,865 lbs. per sq. in.
Remarks.—Pile failed at smaller end, opening oblique and longitudinal cracks.

Attention should be called to the fact that the pile failed at the smaller end and not at the end receiving the hammer blows. This indicates that the pile was not materially damaged by the severe hammering it received, except at the immediate point of contact. An examination of tests of reinforced columns at the Watertown Arsenal shows, for columns of the same proportions of concrete and same age, and reinforced with four longitudinal rods varying from ¾ in. to 1⅛ ins. a range of 2,000 to 3,000 lbs. per sq. in. based on the total cross section of the concrete and steel. It will, therefore, be seen that notwithstanding the severe treatment of the pile in driving, the ultimate strength was considerably higher than the average strength of similar columns. Evidently the strength of the pile was not appreciably affected by the driving or by the crushing of the head.

Cost.—The cost of the materials and the labor are tabulated in detail in Table XI. The labor costs are taken from the timekeeper's record, but are sufficiently subdivided to be useful for other jobs of a different character. The items which vary directly with the number of piles are separated from the costs which are independent of the number of piles, but must be applied to any job as a constant expense. Only a few items depend upon the character of the ground.

The lumber for the forms (except the platform) is assumed to be a constant for any job, because it can be used over and over. The size of the platform must vary with the number of piles.

The pile driver for any one job is figured at 25 per cent of the initial cost for depreciation and interest, but the cost of repairs is included in the items which vary with the number of piles.

The costs which are variable are given per linear foot of pile for subsequent use. It will be seen that the total cost per linear foot of pile on this particular job was about $1.63. If the length of piles differed greatly from those given, it might be necessary still further to separate the cost to provide for this.

A study of the various items taken in connection with a study of the detail times suggests various places where the cost may be altered for other jobs.

For example, an inspection of the costs shows that the cost of the reinforcing steel is over one-third the cost of the piles. From the fact that piles withstood the severe usage given by the pile driving, it is probable, if the piles are not over 30 ft. long, that ¾-in. steel instead of ⅞-in. could be used for the corner rods,

TABLE XI.—COST OF DRIVING PILES ON B. W. H. & R. COMPANY JOB.

		Total.	Per lin. ft. of pile.
(1)	6,000 ft. B. M. plank for platform @ $0.25.4..$ (Lumber cost $25 per thousand and assumed to be used for four times.)	37.50	$0.0256
(2)	350 ft. B. M. for chamfer @ $30...........	10.50	0.0072
(3)	25 lb. spikes for platform @ .03............	.....	......
(4)	20 lb. 9d. @ .03..........................	.....	......
(5)	8 lb. 4d. @ .04..........................	1.67	0.0011
(6)	50 tons crushed stone @ $1.50.............	75.00	0.0512
(7)	18½ yd. sand @ $1.00.....................	18.50	0.0126
(8)	69½ bbl. cement @ $1.82..................	126.49	0.0864
(9)	192 pcs. ⅞ in. by 30 corrugated bars, 15,333 lb., @ 2.65c.........................	406.32	0.2670
(10)	3 4¼-in. bars by 48 piles by 5 ft. 0 in., 1,958 lb., @ 3.00c.........................	58.74	0.0401
(11)	8,160 ft. No. 14 wire, 163 1/5 lb., @ $0.04½	7.34	0.0050
(12)	4 pcs. ½-in. bars by 48 piles by 2 ft. 6 in. = 480 ft. = 408 lbs., @ $2.85.............	11.62	0.0079
(13)	48 2-in. nipples, 12 in. long, @ $0.15.......	7.20	0.0049
(14)	48 2-in. by 1½-in. ells, @ $0.12............	5.76	0.0039
(15)	1,440 ft. g. i. pipe @ $3.51 per 100.........	50.56	0.0346
(16)	48 hooks, @ $0.25........................	12.00	0.0082
(17)	Bending and placing reinforcement........	122.62	0.0838
(18)	Labor on pile platform...................	33.03	0.0226
(19)	Labor on forms...........................	83.72	0.0572
(20)	Labor on concrete........................	111.07	0.0751
(21)	Superintendence	31.20	0.0213
(22)	Pile driving labor.......................	399.42*	0.2722†
(23)	Cutting slot in tip of pile................	3.00	0.0020
(24)	Repairs to pile driver and cushion..........	22.40	0.0152†
(25)	Cutting off broken piles..................	23.51	0.0161†
(26)	Rent of engine...........................	30.00	0.0207
(27)	Superintendence	42.00	0.0286†
	Total cost..............................	$1,731.17	
	Cost per ft. varying with number and length of piles................................		$1.1705
	Items Constant for Each Job.		
(28)	2,800 ft. B. M. plank for pile sides @ 25.4...$	17.50	
(29)	300 ft. B. M. plank for ends @ $25.........	7.50	
(30)	Pile driver 25% of $198.21................	49.55	
(31)	Getting ready, 2 days, @ $30..............	60.00	
(32)	Teaming, pile driver, etc..................	34.55	
(33)	Removing driver..........................	34.61	
	Total cost per job......................$	203.71	0.1391
	Total estimated net cost per lin. ft. job has 48 piles		$1.3096
	Add 25% for pumping, connections, contingencies and profit................................		.3274
			$1.63

*After deducting $60 assumed as constant "getting ready."
†Only items affected by character of ground.

with extra reinforcement near the butt, as in the present case. The size of these rods can be determined by figuring the stress in them during the process of raising the pile to place. The pile is then a beam supported at the ends and carrying its own weight, which must at least be doubled to provide for swaying incident to the

raising. The cost of the item of steel and labor would in such cases be varied accordingly.

The labor on concrete appears large, and might probably be reduced on another similar job from $111 to about $74. This is based on the fact that, while on the average only 6 piles were made, toward the latter part of the making 9 piles were made on one day and 10 piles on another, so that an average of 8 piles should be possible with the given gang. This is especially probable because the cost of making and placing the concrete was $2.32 per pile, or $2.25 per cu. yd., whereas the writer's data on hand mixing indicate that the cost should not have exceeded $1.50 per yd.

With reference to the time and cost of the driving, it must be taken into consideration that the job was a small one, only 48 piles being needed; that the work was of an untried character; and also that the conditions were unfavorable, especially as regards the water pressure. On a large job, in ordinary ground, where large stones or obstructions are not likely to be encountered, the number of piles driven per day should be greatly increased. A study of the detail log of the driving tests and a comparison of these times with detail records taken on other jobs, indicate that the average time per pile driven with the aid of a water jet may be easily reduced to one hour, while if the ground is very soft, the average time per pile, including the moving of the driver, need not be over 40 mins. One hour per pile corresponds to 8 piles per eight-hour day, instead of 3½ piles per day. The estimated time on the items near the foot of the cost table, which is inversely proportional to the total number of piles given, would be decreased on a job having 200 piles from $0.139 to $0.035 per foot of pile. This, together with the reductions noted above, and the assumption of 8 piles driven per eight hours, would bring the estimated cost per linear foot down to $1 net, or, with 25 per cent allowance for pump hose connections, incidentals and profits, to $1.25 per linear foot. In soft ground, and where conditions are specially favorable, a still lower estimate is possible.

A few of the items, such as the nipples and short bars, are constant per pile, that is, are independent of the lengths of the pile, so that in a close estimate for longer or shorter piles they should be separated out or allowed for by inspection.

As it assumed in the estimate in the last column that 5¾ piles are driven in 8 hrs., the total cost for harder or softer ground can be estimated by assuming the number of piles to be driven per day and varying the items marked with a † accordingly.

Records of six of the typical piles are plotted and the curves are shown on the diagram (Fig. 10).

The full curves in Fig. 10 show the portion of the driving where the water pressure was on and the dotted lines the driving after it had been cut off by the filling of the pipe at the tip of the pile. This stoppage was not necessarily due to the design of the pile or to the method of driving, but chiefly to the insufficient capacity of the pump.

The flattening out of the curves indicates difficulties in driving,

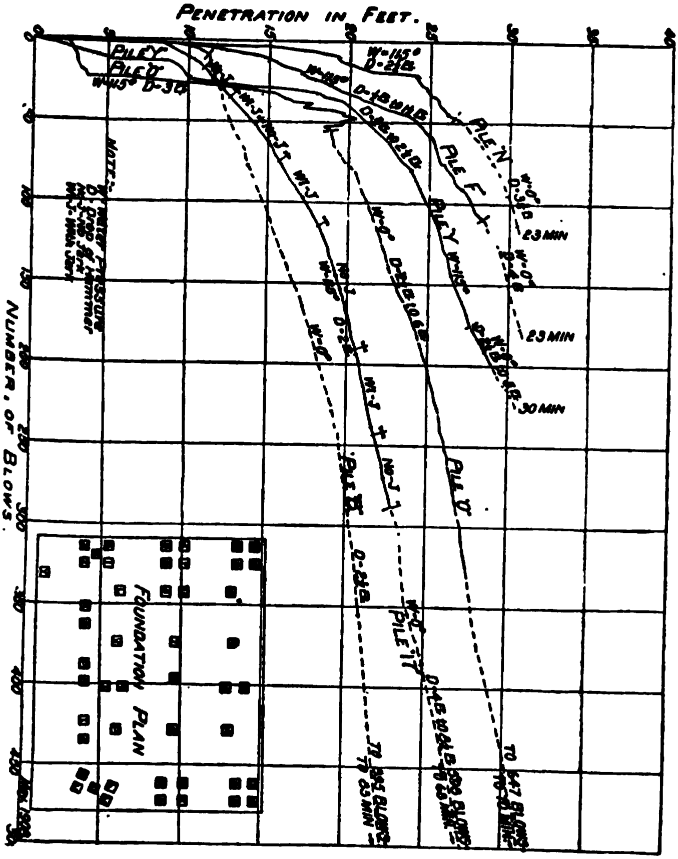


Fig. 10.—Records of Pile Driving.

usually because of the poor water pressure. In certain cases irregularities indicate the striking of obstructions, and when the pile is slightly jerked ground is lost instead of gained.

Curves of piles *N*, *F* and *Y* are given to show good driving, the pressure remaining on most of the time, and the total net time, omitting all unnecessary delays, being from 23 to 30 mins.

Piles *F* and *Y* show also that if a greater drop of hammer had been used at the start they would probably have approached nearer the *N*.

In driving pile *N* at 24-ft. depth, the hammer was allowed just to tap the top of the pile with no impact, and the pile being slightly churned, the loss of progress is shown by slight drop in curve. Then by increasing the height of the blow it started down again. Time, 23 mins. with 118 blows.

On pile *F* they first began jerking the pile after each blow, and this method appears to be effective provided ground is soft enough actually to lift pile readily. In hard ground it is ineffective. Drop of hammer was increased from 0.5 to finally 4 ft. Time driving 24 minutes with 185 blows.

Pile *Y* was not churned or lifted after first blow or two, but went down with light blows. Time, 30 mins., 225 blows. Pressure good.

The curve of pile *B* is given to illustrate hard driving, due to lack of water pressure. The water pressure stopped at 11½-ft., as shown by the sudden break in curve at this point. Total time driving pile was 83 mins. with 895 blows.

In the curve of pile *O* there is an interesting break at the depth of about 20 ft., where an effort was made to assist the pile by churning or jerking, and ground was lost by doing so, and the pipe was also allowed to plug. As soon as the hammer was allowed to drop in the usual way the penetration began again, but 647 blows and 70 mins. by net time were required to carry it to its full depth. At a depth of 2½ ft. an obstruction was met, as indicated by the curve, and a small broken piece of timber came up beside the pile. Another reason for the flat curve of pile *O* is that the ground was unusually hard.

Pile 17 was driven in an experimental fashion to determine the effect of the jerk at the end of each blow. The curve is uniform throughout, showing that this jerk is absolutely ineffective in hard ground. In this pile, as noticed, the height of drop was increased to 8½ ft.

Cost of Reinforced Concrete Piles for an Ocean Pier.*—In reconstructing in reinforced concrete the old steel pier at Atlantic City, N. J., some 116 reinforced concrete piles 12 ins. in diameter were molded in air and sunk by jetting. The piles varied in length with the depth of the water, the longest being 34½ ft. Their construction is shown by the accompanying drawing (for these drawings see Gillette and Hill's "Concrete Construction"), which also

***Engineering Contracting*, Nov. 28, 1906.

show the floor girders carried by each pair of piles and forming with them a bent, and the struts bracing the bents together. In molding and driving the piles the old steel pier was used as a working platform.

The forms for the piles were set on end on small pile platforms located close to the positions to be occupied by the piles and were braced to the old pier. The forms were of wood and the bulb point, the shaft and the knee braces were molded in one piece. Round iron rods were used for reinforcement. The concrete was composed of 1 part Vulcanite Portland cement, 2 parts of fine and coarse sand mixed and 4 parts of gravel 1 in. and under in size. The mixture was made wet and was puddled into the forms with bamboo fishing rods, which proved very efficient in working the mixture around the reinforcing rods and in getting a good mortar surface. The concrete was placed in small quantities; it was mostly all hand mixed. The forms were removed in from 5 to 7 days, depending on the weather.

The piles were planned to be sunk by water jet and to this end had molded in them a 2-in. jet pipe as shown. They were sunk to depths of from 8 ft. to 14 ft. into the beach sand. Water from the city water mains at a pressure of 65 lbs. per sq. in. was used for jetting; this water was furnished under special ordinance at a price of $1 per pile, and a record of the amount used per pile was not kept. The piles were swung from the molding platforms and set by derricks and block and fall. The progress of jetting varied greatly owing to obstructions in places in the shape of logs, old iron pipes, etc. In some cases several days were required to get rid of a single pipe. In clear sand, with no obstructions, a 12-in. pile could be jetted down at the rate of about 8 ft. per hour, working 1 foreman and 6 men. The following is the itemized actual cost of molding and sinking a 26-ft. pile with bulb point and knee braces complete:

	Total.	Cost per pile.
Forms.		
Lumber, 340 ft. B. M. @ $30	$10.20	....
Labor (carpenters @ $2.50 per day)	12.00	....
Oil, nails, oakum, bolts, clamps, etc.	1.20	....
	$23.40	$ 3.90
Times used	6	....
Reinforcement.		
275 lbs. of plain ¾-in. steel rods @ 2 cts. per lb.	$ 5.50	....
Preparing and setting, 4/10 ct. per lb.	1.10	6.60
Jet Pipe.		
26½ ft. of 2-in. pipe @ 10 cts. per ft. in place	...	2.65
Setting Forms.		
6 men @ $2.50 per day = $15, set 4 piles	...	3.75
Material.		
90/100 cu. yds. gravel @ $1.50 per yd.	1.35	....
45/100 cu. yds. sand @ $1.50 per yd.	.67	....
1.50 bbls. cement @ $1.60	2.40	4.42

Labor.		
Concrete and labor foreman..............	3.00	....
6 laborers, mixing and placing by hand, $1.75 each..........................	10.50	....
	$13.50	$ 3.38
Average number of piles concreted per day	4	....
Removing Forms.		
4 men @ $2.50 remove and clean in half day 4 columns......................	...	1.25
1 man @ $2.25 plastering column with cement grout (4 per day)..............	...	.56
Jetting 10 ft. into Sand.		
Foreman	$ 3.00	....
4 men, $2.25 each, handling hose and traveler	9.00	....
	$12.00	$ 3.00
Average number of piles jetted per day...	4	....
City water pressure used for jetting @ $1.00 per pile.......................	...	1.00
Superintendence @ $5.00 per day........	...	1.25
Caring for trestle, traveler, material, etc.	...	4.84
Total cost per pile....................	...	$36.60

The pile being 26 ft. long, the cost in place was $1.41 per foot. Subtracting the cost of sinking, amounting to $7.09 per pile, we have the cost of a 26-ft. pile molded and ready to sink coming to about $1.10 per foot. It should be noted that this is the cost for a pile of rather complicated construction; a plain cylindrical pile should be less expensive.

During a visit to Atlantic City one of the editors of this journal took occasion to examine closely these 12-in. piles. They were then about four or five months old, and were in all respects as sound and smooth examples of concrete work as could be wished. The surface texture of the piles was notably good; the piles appeared to have a surface film or skin which he then took to be some saline incrustation coming from the sea water. A statement since received from Mr. D. A. Keefe Consulting Engineer, Athens, Pa., who was resident engineer of the pier work, and to whom we are indebted for the figures of cost given above, mentions that the piles are covered with a coating of organic and inorganic nature which fills the pores of the concrete and will in time form a coating of considerable thickness which should have the effect of shutting out the sea water and preventing any disintegration. In conclusion, it should be noted that the design of the concrete steel work employed in reconstructing this pier was worked out by the Concrete Steel Engineering Co., of New York City, and that the contractors for the work were C. W. Snyder & Co., of Atlantic City, N. J.

Cost of a Reinforced Concrete Pile Dike.*—The work described is a reinforced concrete pile dike built opposite St. Joseph, Mo., on the Missouri River improvement work. This is the first dike of reinforced concrete to be constructed on the Missouri River and

**Engineering-Contracting,* Oct. 20, 1909.

is an experiment to secure a better and more durable structure than is provided by the usual timber pile dike having a life of from 7 to 10 years. Several plans were considered and are described by Maj. Edward H. Schulz.

The plans considered besides the one adopted were: (1) Sinking a core with shell, withdrawing core, and filling the shell with concrete; (2) casting the pile in place, the form being gradually removed as the filling proceeds; (3) rolling and making the pile on the ground by special machine. The adopted plan was to use cast piles of rectangular or octagonal section and to drive them by hammer and water jet combined. Bids were asked for supervising the work and furnishing forms and reinforcement, the Government to furnish all other materials, to make the piles and to drive them. The lowest bid was 80 cts. per lin. ft. of pile.

The dike structure consists of 3-pile bents connected at tops of piles, and at about water level with horizontal transverse and longitudinal braces. The length of the dike is 150 ft., of which 40 ft. at the shore end consists of timber piles. A length of 110 ft. was constructed of concrete piles. The bracing was all wood except in two panels, where as an experiment concrete braces were used. The total number of concrete piles was 36, varying in length from 32 to 50 ft., and having a total length of 1,457 lin. ft. The piles were 14 ins. square at top and 8 ins. square at the point. Each was reinforced with 4 1-in. bars tied every 18 ins. with 1¼-in. bars. The concrete was a 1 : 2 : 4 mixture, using Ash Grove Portland cement and 1-in. stone. The piles were driven at the age of 10 days; the average penetration was 21 ft.

The piles were cast on a foreshore at an elevation of about 6 ft. above the deck of a barge in the river. Skids were placed from the foreshore to the barge, and as the forms were removed the piles were slid on-board, somewhat similar to the handling of wooden timbers of like size. The approximate weight of a 50-ft. pile is 8,700 lbs.

On account of the excessive weight of these piles over wooden piles of the same length, wire cable was used, using a single and double block for increasing the purchase. The hitch for raising the head of the pile was placed about 8 ft. from head. The ordinary pile line was used to raise the point of pile, the sling being placed about 15 ft. from the small end of pile. This arrangement takes the spring out of the pile. The catenary of a 50-ft. pile is about 5 ins. without injury to pile.

A device, known as a guide, was placed around the pile near the head in such manner as to hold the pile squarely in the leads. The pump used was a single cylinder, double action, 6-in. suction, 8-in. discharge, 1¼-in. nozzle, 60 strokes per min., and 80 lbs. steam pressure. A piece of 1¼-in. pipe was placed in the end of the pile, to which the jet was attached. Other than this the method of sinking was the same as for wooden piles of like size.

The piles were driven near shore, where unusual difficulties existed, due to parts of old dike and rock buried in river bed. Under

normal conditions, where only sand is encountered, the pile was jetted in 3 to 5 mins.; no hammer was used, but occasionally the pile itself was lifted and dropped to hasten the work. It is believed a judicious use of jet and hammer will be found advisable for future work.

This dike was examined after going through an ice and flood season and was found to have stood very satisfactorily. Not a pile or concrete brace was injured, though several wooden braces were broken. Should results continue with similar success, it is probable that concrete dikes will receive serious consideration as a permanent substitute for timber piles on river regulation.

The cost of the dike was as follows:

Item.	Total.	Per lin. ft.
Supervising, forms and steel rods....	$1,200.00	$0.8236
86¾ bbls. cement at $1.25...........	108.44	0.0743
55.9 tons crushed stone at $1.30.....	72.67	0.0498
32 cu. yds. sand at 20 cts............	6.40	0.0043
Labor on forms.....................	117.00	0.0803
Labor making piles.................	257.70	0.1768
Labor driving piles..................	215.00	0.1475
Total	$1,977.21	$1.3566

In regard to these figures Mr. Schulz says: "The actual cost, deducting profit of contractor and cost of special supervision, would be $1 per ft. On extensive work this could probably be reduced to 40 cts. per lin. ft. of pile, as compared to 20 cts. for long-leaf yellow pine."

Cost of Raymond Concrete Piles.*—The following figures of the cost of constructing concrete piles by the Raymond process have been computed from records obtained in constructing the pile foundations for the concrete laundry building of G. L. Hooper & Sons, of Salem, Mass. The building is of concrete throughout, the walls being of concrete block and the columns, floors and roofs of reinforced concrete. There are four stories and the general dimensions are 60 x 100 ft. The floor and wall loads are transferred to wall columns and to two rows of interior columns. The columns are spaced 14 ft. apart on centers in one direction and 19 ft. in the other direction. Each column and its footing rests upon four concrete piles spaced 3 ft. apart on centers in the form of a square. The spandrels between wall columns are reinforced concrete. The groups of four piles are each capped with a concrete slab 5 ft. 6 ins. square and 24 ins. thick, making the projection of the capping beyond the center of the piles 15 ins. Each pile was finished so as to allow a projection into the capping of 6 ins. A concrete chimney, 48 ins. in diameter and 100 ft. high, located at one corner of the building, is supported upon a group of nine piles. Each of these piles has embedded in it a steel rod which projects into the walls of the chimney, forming an anchorage.

As firm bearing soil was some distance below the ground, piling of some sort was necessary, and wood piles were originally consid-

**Engineering-Contracting*, Feb. 13, 1907.

ered. This would have made it necessary to cut off the wood piles below low tide, a distance of 12 ft. below the level of the ground floor, and using a large amount of concrete in the stepped footings above. Instead, concrete piles were used which were cut off 5 ft. below the ground floor, effecting considerable saving of concrete foundations. Another feature which made the use of concrete piles desirable in this instance was the fact that the site of the building was formerly occupied by an old wharf, the timbers of which were many of them yet in the ground. Had wood piles been used, difficulties would probably have been experienced due to the "brooming" of the piles when striking such obstructions. With the steel driving form used for the concrete piles, delays from this source were avoided. The piles are designed for a load of 30 tons each, and each takes the place of two wooden piles in the original design. They are 6 ins. in diameter at the small end and have a uniform taper each side of the center of ½ in. to a foot, making a 21-ft. pile 20 ins. in diameter at the top.

In constructing concrete piles by the Raymond process, as many of our readers will remember, a thin steel shell enveloping a metal core is driven and then the core is collapsed and withdrawn, leaving the shell, which is afterwards filled with concrete in which metal is embedded if a reinforced pile is desired. In this particular work no reinforcement was used in the piles.

The piles were driven by means of a No. 2 Vulcan steam hammer, with a plunger having a weight of 3,000 lbs. and a fall of about 3 ft., delivering 60 blows per min. A steel driving form encased in a shell of about No. 20 gage iron was first driven to the required depth; the steel driving form was then withdrawn, leaving the shell in place, and the concrete afterwards deposited in this shell. A total of 172 piles were driven, the minimum length being 14 ft. and the maximum 37 ft., the average being about 20 ft. Sixteen working days were occupied in driving the piles after the driver was in position, driving being commenced Aug. 17 and completed Sept. 6, 1906. The greatest number driven in one day was 20, and the average was 11 piles per day. When in position for driving the average time required to complete driving was 12 mins. The total number of blows varied from about 310 to 360, the average being about 350. The piles were driven until the penetration produced by 8 to 10 blows equalled 1 in. When in full operation, a crew of 5 men operated the pile driver. Seven men were engaged in making the concrete and 5 men working upon the metal shells.

Assuming the ordinary organization and the wages given below, we have the following labor cost per day:

1 foreman at $5	$ 5.00
1 engineman at $3	3.00
4 laborers on driver at $1.75	7.00
6 laborers making concrete at $1.75	10.50
5 laborers handling shells at $1.75	8.75
Total	$34.25

As 172 piles averaging 20 ft. in length were driven in 16 days,

the total labor cost of driving, given by the figures above, is 16 × $34.25 = $548, or practically 16 cts. per lin. ft. of pile driven.

The concrete used in the piles was a 1 : 3 : 5 Portland cement, sand and 1½-in. broken stone mixture. A 20-ft. pile of the section described above contains about 20 cu. ft. of concrete, or say 0.75 cu. yd. We can then figure the cost of concrete materials per pile as follows:

0.85 bbl. cement at $1.60	$1.36
0.36 cu. yd. sand at $1	0.36
0.60 cu. yd. stone at $1.25	0.75
Total per pile	$2.47

The steel shell has an area of about 72 sq. ft., and as No. 20 gage steel weighs 1.3 lbs. per sq. ft., its weight for each pile was about 94 lbs. Assuming the cost of coal, oil, etc., at $2.50 per day, we have the following summary of costs:

	Per lin. ft. of pile.
Labor driving and concreting	$0.16
Concrete materials	0.123
94 lbs. steel shell at 3 cts.	0.145
Coal, oil, etc.	0.011
Total	$0.439

This cost does not include interest on plant, cost of moving plant to and from work and general expenses, nor royalty on the Raymond patent.

The contract was awarded for a fixed number of lineal feet of pile at the rate of $1.50 per lin. ft., with a provision for additional length of piling to be furnished at $1.40 per lin. ft., the contractors providing all tools, machinery, material and labor required for the work. The owners, through the contractor for the building proper, made the necessary excavations and provided clear and level space for the pile driver, braced all trenches.

For the cost of Raymond piles at another place, see "Concrete Construction" by Gillette and Hill.

Cost of Rolled Concrete Piles.*—The abutments of the Chicago & Northwestern Ry. bridge over the Root River at Racine, Wis., are founded on reinforced concrete piles manufactured by the Chenoweth rolling process. The cost of these piles is given by Mr. L. C. Winkelhaus as follows: "The contract price for these piles was 60 cts. per lin. ft., or $9.60 per pile 16 ft. long. The railway company furnished all the materials, costing $6.46 per pile, or 40 cts. per ft. The general contractor received 50 cts. per ft. for driving, or $8. Hence, the cost to the railway company was $24.06 per pile in place, or $1.50 per ft. The cost to the American Concrete Co. for rolling was 25 cts. per ft., or $4 per pile, approximately. The machine and plant cost the concrete company about $3,000. However, this machine can be moved from place to place and used a great many times, as it is all bolted together."

*_Engineering-Contracting_, Aug. 18, 1909.

The method of making concrete piles by rolling, and detailed cost, will be found in "Concrete Construction" by Gillette and Hill.

Cost of Simplex Piles.—Mr. Constantine Shuman gives the following relative to work done in Pittsburg in 1904:

One gang working on Simplex piles 30 ft. long averaged 450 lin. ft. per day, or 15 piles, but the best day's work was 31 piles, or 930 lin. ft. The crew was as follows, and I have assumed rate of wages, etc.:

	Per day.
1 foreman	$ 4.00
1 engineman	3.00
2 winch head men, at $1.75	3.50
3 riggers, at $2.00	6.00
Total pile driver gang	$16.50
6 concrete mixers, at $1.75	10.50
Total gang	$27.00
Rent of driver and apparatus, and fuel	18.00
Total, exclusive of materials	$45.00

This is equivalent to 10 cts. per lin. ft.

The piles are 17 ins. diameter, composed of 1 : 2½ : 5 mixture. There are 1.58 cu. ft., or 0.059 cu. yd. per lin. ft. of pile.

For description of methods of making Simplex piles and the special pile points, see Reid's "Concrete and Reinforced Concrete Construction."

Cost of Concrete Oil Tank.*—Mr. C. F. Leonard gives the following data:

The wall forms a building housing a circular steel oil tank; it is 42 ft. inside diameter, 25 ft. high and 12 ins. thick. The reinforcement consists of ⅞-in. twisted steel rods located 2 ins. inside the exterior face and spaced apart from 3½ ins. at the bottom to 30 ins. at the top. Vertical rods 9 ft. apart around the wall held the horizontal rods in place. To tie the wall to the bottom L-shaped ½-in. rods 7 ft. long were used. Lap splices 33 ins. long were employed.

The forms were made in panels 6 x 8 ft., of ⅞-in. spruce boards 6 ins. wide dressed on one side and both edges and nailed to three segments of 2 x 12-in. plank cut to curve. For the first three shifts the forms were braced on both sides. A ½-in. rope with turnbuckles was passed around the steel tank, and the forms were drawn against spacing blocks, set between the steel tank and the inside form and also between forms, by wire ties fastened to the wire rope. The outside panels were also braced from the ground. Above this level the panels were held in position by bolts through the concrete wall.

The concrete for the bottom 15 ft. of the wall was a 1 : 2 : 3½ 1-in. stone mixture; above this level the cement content was reduced. It was mixed wet by hand and wheeled up inclines to the tops of the forms. The first ring 5½ ft. high, was concreted in one day; afterwards the forms were shifted for about one-third the circumference at a time and the concreting was done in a spiral course.

*Engineering-Contracting, Oct. 21, 1908.

Grooved joints were made whenever work was stopped. Frames for windows and doors were cast separately and set in place as the concreting progressed. The wall was painted with two coats of neat cement both inside and outside.

The cost of the wall was as follows:

Item.	Per cu. yd.
Cement at $1.70 per bbl.	$ 2.81
Sand at $1.35 per cu. yd.	0.66
Stone at $1.20 per ton	1.42
Labor at $1.75 per 9 hrs.	4.25
Reinforcement	1.65
Lumber, nails and supplies	1.46
Carpenters' labor	5.25
Total	$17.50

The cost of carpenter work was over twice what it should have been, owing to local conditions.

Cost of Concrete Tanks, References.—See section on Waterworks for data on this subject. Also see Chapter XXI, Methods and Cost of Construction Reservoirs and Tanks, in Gillette and Hill's "Concrete Construction."

Cost of Small Cement Pipes.*—Mr. Albert E. Wright is author of the following: The pipe discussed here was 6 to 12 ins. inside, made of Portland cement and clean, sharp sand of all sizes up to very coarse. The mortar was mixed rather dry, but very thoroughly, using 14.1 cu. ft. of sand to 1 bbl. of cement, or very closely a 1 to 4 mixture. From six to seven buckets of water were used to each barrel of cement, except for the 6-in. pipe, for which the mortar had to be made somewhat stiffer in order to remove the inner form, which is not made collapsible as in the larger sizes.

The forms were sheet iron cylinders with a longitudinal lap joint that could be expanded after molding the pipe, and removed without injuring the soft mortar. The inner form was self-centering, so that there was little variation in the thickness of the pipe.

Four men are required in making cement pipe by hand; one mixes the mortar, and wheels it to the place of work; another throws it into the form a little at a time with a hand scoop; a third rams it with a tamping iron, and a fourth keeps the new pipe sprinkled, and applies a coat of neat cement slurry to the inside when it is sufficiently hard. In molding, the form of the bell at the bottom is secured by an iron ring that is first dropped into the form, and the reverse or convex form at the top is made with a second ring. While still in its form the pipe is rolled or lifted into its place in the drying yard, and the form is then carefully removed. A very slight blow in removing the form will destroy the pipe, and a considerable number, especially of the larger sizes, collapse in this way, and have to be remolded. To avoid handling, the pipe is stacked on end a few feet from the place of mixing, the form being moved as the yard fills with pipe. One crew of four men can make about 250 joints or 500 lin. ft. of pipe a day.

*Engineering-Contracting, Dec. 4, 1907.

As soon as hard enough, the pipe is turned end for end, and is then kept wet for several weeks before being laid. The coating of neat cement on the inside is applied with a short whitewash brush, and is a small item in the cost. In laying, the trench is carefully finished to grade in order to have the joints close nicely, and the ends are well wet with a brush. The mason then spreads mortar, mixed 1 to 2, on the end of the pipe, and lays a bed of mortar at the bottom of the joint. He then jams the section into place, and swabs out the inside of the joint with a stiff brush, to insure a smooth passage for the water. A band or ring of mortar is spread round the outside of the joint as an additional reinforcement. One barrel of cement will joint about 300 sections of pipe. The materials cost as follows: Portland cement, per bbl., \$4.45; labor, per day, \$2; foremen, per day, \$2.50 to \$3; hauling, per load mile (1 cu. yd.), 20 cts.; sand, free at pit; water, free.

The pipe was all of a 1:4 sand and cement mortar, and the amount of cement in one foot of pipe is arrived at by assuming as in Gillette's "Hand Book of Cost Data" that where the sand has voids in excess of the cement used, the mortar will occupy 1.1 times the space of the dry sand, which yields the following formula: Where—

c = cost per bbl. of cement, or \$4.45.
n = cu. ft. in one bbl. (taken at 3.5 here).
s = ratio of sand to cement, or 4.
d = inside diameter in inches.
t = thickness of pipe in inches.
l = length of pipe considered, or 1 ft. here.

Then:

$$\text{Cement-cost per foot} = \frac{c \times l \times \pi \times (dt + t^2)}{n \times s \times 1.1 \times 144},$$

$$\text{which gives here} = \frac{4.45 \times 1 \times 3.142\,(dt + t^2)}{3.5 \times 4 \times 1.1 \times 144}$$

$$= 0.00631\,(dt + t^2).$$

This gives the following cement costs per lineal foot:

Diameter, ins.	Thickness, ins.	Cost per foot.
6	1¼	\$0.0571
8	1¼	0.0730
10	1⅜	0.0998
12	1½	0.1278

The sand cost is based on 15 cts. per cu. yd. for loading, and a haul of two miles of 1 cu. yd. to the load, making five trips per day, at \$4 for man and team. It bears a constant ratio to cement cost, being 11.2% of the cement cost. The labor cost of making is based on the foreman's estimate that a foreman, tamper, mortar mixer, and water man should finish 250 joints a day of 6 or 8-in. pipe. For the 10 and 12-in. pipe, the labor is assumed to be greater in proportion to the material. The foreman is taken at \$3, one man at \$2.50 and two at \$2. The cement for painting the inside is neglected. Hauling the pipe to place is taken at twice the cost of hauling the

sand per mile, and a haul of 4 miles is assumed. The cost of laying is based on a foreman's estimate of 2 cts. per foot for trench, and that one man to lay, one man to plaster the joints, one helper and one man to backfill will lay 600 ft. per day of 6 or 8-in. pipe. The larger sizes are assumed to cost more in proportion to their material.

These various costs give the following results for small size pipe as made and laid at Irrigon, Ore., for the Oregon Land & Water Co.:

	Cost per foot for			
	6-in. pipe.	8-in. pipe.	10-in. pipe.	12-in. pipe.
Cement	$0.057	$0.073	$0.099	$0.128
Sand	0.006	0.008	0.011	0.014
Labor	0.019	0.019	0.026	0.034
Hauling	0.024	0.032	0.044	0.056
Laying	0.024	0.024	0.032	0.042
Trench	0.020	0.020	0.020	0.020
Totals	$0.15	$0.18	$0.23	$0.29

The above costs show that the pipe in place costs about twice as much as pipe in the yard, even with cement at $4.45, and illustrates the danger of accepting cement manufacturers' estimates without examining local conditions, especially as to handling.

(For further data on cement pipes, see the sections on Waterworks and on Sewers.)

Cost of Concrete Pipe.*—The following estimates of cost of concrete pipe manufactured by force account on the Shoshone Project are based on the results of five days' work in November, 1907. The cost of cement was $3.05 per bbl., of sand about $1.40 per cu. yd., and of labor $5 per day for 1 foreman, $3 per day each for 2 men and $2.75 per day each for 2 men. Plant depreciation and administrative expenses are not included in the unit costs given. The concrete was made of 1 part cement and 3 parts sand. The size and the thickness of the pipe, the weight and the unit cost per linear foot thereof and the number of linear feet manufactured in the five days are tabulated below:

Diam. Ins.	Thick. Ins.	Wt. per lin. ft. Lbs.	No. ft. made	Cost per ft.
12	1½	56	144	$0.25
18	1¾	94	248	0.37
24	2	143	56	0.57
36	3	366	54	1.15

Cost of Cement and Concrete Pipes and Sewers, References.—See the sections on Waterworks and on Sewers. See Chapter XXI. Methods and Cost of Aqueduct and Sewer Construction in Gillette and Hill's "Concrete Construction."

Cost of a Band Stand.—Mr. W. F. Creighton gives the following data:

The band stand was built much like a mushroom, the roof being 32 ft. in diameter, supported by a central post. The floor was concrete also. The concrete was a 1 : 2 : 4 stone dust, ¾ to 1¼-in. broken stone mixture. It was mixed by hand and hoisted in wheel-

*Engineering-Contracting, March 18, 1908.

barrows by means of a gallows frame and snatch block operated by a mule. The forms for the shaft and underside of the stand consisted of steel plates nailed to vertical radial ribs built to the designed curve. These ribs were made of 2-in. lumber. Toward the upper ends where the radial spread between ribs was largest cross-struts were built between ribs. The outer ends of the ribs were supported by staging; they were also braced at the tangent points on the center column or stem. The amount of concrete was 80 cu. yds. and it cost as follows:

Materials.	Total.	Per cu. yd.
119 bbls. cement at $2.65	$ 319.95	$ 3.95
40 cu. yds. stone dust at $1.10	44.00	0.55
80 cu. yds. broken stone at $1.10	88.00	1.10
5,500 lbs. reinforcement	229.00	2.86
2,500 ft. B. M. lumber and shopwork	76.21	0.95
Total	$ 754.16	$ 9.41
Labor.		
Mixing and placing concrete	$ 171.00	$ 2.14
Bending and placing steel	40.00	0.50
Falsework and wood forms	113.90	1.43
Steel forms (labor and material)	164.00	2.05
12-in. pipe (furnishing and erecting)	86.25	1.08
Unloading and hauling stone ½ mile	60.00	0.75
Finishing	12.00	0.16
Excavating	5.00	0.06
Total	$ 652.15	$ 8.17
Superintendence	42.00	0.53
Foreman	39.00	0.48
Total	$ 81.00	$ 1.01
Grand total	1,487.31	18.59

Cost of Sylvester Wash and Sylvester Mortar.—Mr. W. C. Hawley is authority for the following: A covered concrete clear water well of the Apollo Water-Works Co. leaked, so it was plastered with a Sylvester mortar. A light-colored soft soap was dissolved in water, 1¼ lbs. soap to 15 gals. of water. Then 3 lbs. of powdered alum were mixed with each bag of cement. The mortar was 1 : 2. Two coats of this plaster were applied to the dry walls, giving a total thickness of ½ in. Leaking was thus stopped completely. The cost was:

2 lbs. soap (with 24 gals. water), at 7½ cts.	$0.15
12 lbs. alum, at 3½ cts.	0.42
Total	$0.57

Or 57 cts. for soap and alum per barrel of Portland cement.

In repairing the bottom of a reservoir lined with 4 to 6 ins. of concrete which leaked, a Sylvester wash was used. The soap solution was ¾ lbs. of Olean soap to 1 gal. of water, and the alum solution was ½ lb. alum to 4 gals. water; both well dissolved, soap solution being boiled. On the clean dry concrete the boiling hot soap solution was applied; 24 hrs. later the alum wash; 24 hrs. later the soap wash; 24 hrs. later the alum wash. Two men applied the solutions, using whitewash brushes, while a third man carried pails of the solution. In making the soap solution 2 men attended 4

kettles, 1 man kept up fires, 2 men carried solution to men applying it. The alum solution required fewer men, being made cold in barrels. After applying the second soap wash to the concrete slopes, men had to be held by ropes to keep from slipping. The rope was placed around two men, who started work at top of the slope, a third man paying out on the rope. The work was done in 8½ days, and the cost as follows:

Labor.	
1,140 hrs. labor at 15 cts.	$171.00
83 hrs. foremen at 30 cts.	24.90
83 hrs. waterboy at 6 cts.	4.98
Add for supt. 15%	30.13
Total labor	$231.01
Materials.	
900 lbs. Olean soap at 4⅓ cts.	$ 39.00
210 lbs. alum at 3 cts.	6.30
6 whitewash brushes (10-in.), at $2.25	13.50
6 stable brushes, $1.25	7.50
Total materials	$ 66.30
Total labor and materials	297.31

This covered 131,634 sq. ft., hence the cost of the two coats of soap and alum was $2.26 per 1,000 sq. ft., or 0.23 ct. per sq. ft. All leaks but one from a slight crack were stopped.

The concrete lining of a new reservoir near Wilmerding was waterproofed by using caustic potash and alum in the finishing mortar coat. The stock solution was 2 lbs. of caustic potash, and 5 lbs. of alum to 10 qts of water. This was made in barrel lots, from which 3 qts. were taken for each batch of finishing mortar, which consisted of 2 bags of cement mixed with 4 bags of sand; a batch of mortar covered an area 6 ft. x 8 ft. 1 in. thick. The extra cost of this waterproofing was:

100 lbs. caustic potash at 10 cts.	$10.00
70 lbs. caustic potash at 9 cts.	6.30
960 lbs. alum at 3¼, 3¾ and 4 cts.	34.38
60 hrs. mixing at 15 cts.	9.00
Freight, express and hauling	11.50
Total for 74,800 sq. ft.	$71.18

So the cost was 95 cts. per 1,000 sq. ft., or less than 0.1 ct. per sq. ft. Hence the cost was less than by using Sylvester's wash and the result was better, for with Sylvester's wash the penetration is only 1/16 to ⅛-in. It was found that if less than 2 parts of sand to 1 part of cement were used the mortar cracked in setting. Clean sand was imperative as any organic impurities soon decomposed, leaving soft spots. Do not use an excess of potash; a slight excess of alum, however, does not decrease the strength of the mortar.

Cost of Waterproofing With Tar Felt and Asphalt.*—The following data relate to the cost of waterproofing the concrete on the Long Island R. R. subway:

The specifications for the waterproofing will be found in Gillette and Hill's "Concrete Construction."

**Engineering-Contracting*, July 18, 1906.

During the year 1903 there were laid 9,056 sq. yds. of this waterproofing on the roof of the subway. The labor cost of placing the two layers of felt and the three coats of tar pitch was as follows: 206 days labor at a cost of $498 (or an average of $2.41 per day) for the 9,056 sq. yds., which is equivalent to 5½ cts. per sq. yd. for the labor. Since this is for two layers of felt, the labor cost was 2¾ cts. per sq. yd. of single layer, which is a high cost as we shall see presently.

The labor cost of mixing and placing the 1-in. layer of cement mortar over the felt was as follows: It required 589 days, at a cost of $1,306 (or an average of $2.22 per day) to place this 9,056 sq. yds. of cement plaster, which is equivalent to 14½ cts. per sq. yd.

The total cost of labor for the two layers of tar felt and the layer of cement mortar was, therefore, 20 cts. per sq. yd. on this Long Island R. R. work.

For comparison, we will now repeat some of the cost data given in our February issue, relating to the New York Subway. On the New York Subway, the specifications were somewhat similar, except that no mortar coat was specified. The roof of the New York Subway was waterproofed with four layers of asphalt felt and asphalt. The floor of the subway made two layers of asphalt felt placed between two layers of concrete. We may say, therefore, that the average number of layers of felt used in waterproofing the New York Subway was three. The records of cost for this work were kept in terms of one layer of felt, so that it is necessary to multiply the following costs by three in order to get the cost of the three layers. For estimating the quantities of materials used, the following rules were deduced:

Reduce the area to square yards, and add 15% for laps, to obtain the square yards of asphalt felt per single layer.

Multiply the square yards by 0.37 to get the number of gallons of asphalt per single layer of felt.

Where brick are laid in asphalt, allow 650 brick per cu. yd.; and multiply the number of cubic yards of brick by 0.3 to get the number of tons of mastic.

The cost of some 98,000 sq. yds. waterproofing on the New York Subway, was as follows per single thickness of felt:

	Per sq. yd. (single). cts.
1.11 sq. yds. asphalt felt at 4½ cts.	5
0.37 gal. asphalt at 12 cts.	4½
Labor	5½
Total	15

This is for one thickness of felt, so that for 3 thicknesses the cost would be 45 cts. per sq. yd. for labor and materials. Both the labor and materials were high in cost. The labor was high because the men were poorly supervised. There were 2 waterproof "foremen" at $3 per 8-hr. day, and 7 waterproofers (laborers) at $1.50 per day, so that the average wage was $1.83 per day. The "foremen" were skilled waterproofers who worked with the gang.

The material was high priced, because asbestos felt dipped in asphalt was specified. The felt weighed 10 lbs. per 100 sq. ft.

To illustrate how unusually inefficient the waterproofers were, the following records are given. These records were kept by the writer, and relate to the waterproofing of brick walls. The wall was built up one brick thick (4 ins.), and was then waterproofed with three layers of tar felt mopped with tar pitch. The layers lapped on one another like the shingles of a roof, the exposed face of each layer being 1 ft. wide. Three men were engaged in the work: one man melted and carried the tar in buckets, one man mopped it on, and the third man laid the tar felt. The bricks were first mopped with tar, then the felt was laid on and mopped with tar; then a second layer of felt, and so on. The two men mopping and laying felt easily averaged 120 sq. yds. in 8 hrs. Since this was 3-layer work, the men averaged 360 sq. yds. of single layer per day. Skilled roofers were employed placing and mopping the felt at $3.75 a day, and the laborer helping them received $2 a day, so that the gang received $9 for 360 sq. yds., or 2½ cts. per sq. yd., wages averaging $3 per 8-hr. day per man engaged. As a matter of fact, only one skilled man was needed; and, had there been enough work to do, one laborer could have melted and delivered enough tar for two gangs. It usually requires about ⅓ gal. tar per layer of felt, which would mean 120 gals. of tar per day per gang of two men laying. Tar weighs about as much as water, or 8⅓ lbs. per gal., hence 1,000 lbs. tar would be used by the gang of two men in a day. [In the Waterworks section of this book will be found the cost of waterproofing a large reservoir. This work was done on a large scale. Two men heated and delivered the asphalt to one man who spread it with a mop made of twine. The man with the mop spread 5,000 lbs. of asphalt per day of 10 hrs., covering an area of 1,000 sq. yds., which is equivalent to 0.6 gal. per sq. yd. Since two men boiled and delivered the asphalt, each of these two men averaged 2,500 lbs. or 300 gals. per day. It took one cord of wood to boil about 20,000 lbs., or 2,400 gals., from which it will be seen that the item of fuel is practically negligible.]

While men engaged in mopping tar or asphalt over layers of felt cannot be expected to accomplish as much work as men mopping tar over an extended area, still comparisons such as the above are valuable because they show where money may be saved. In this instance the comparison shows that a man boiling and delivering tar is not kept busy unless he is handling at least 300 gals. a day.

When one man is mopping on the tar and a second man is laying the felt, one of the two is usually idle while the other is busy. Provided each man works with great rapidity when he is actually working, very little time is really lost; but, if left to themselves, the workmen will take a very slow gait, and thus more than double the cost.

Finally, unless labor unions interfere, there is really no need of high-priced labor on work of this character. Common laborers can be used for all work except laying the felt, and, even in that work,

a grade of skill only slightly above the average of the common laborer is needed.

As for the felt itself, there is no necessity of anything better than a good grade of tar felt weighing about 15 lbs. per 100 sq. ft., and costing about 1½ cts. per lb., or 2 cts. per sq. yd. We are speaking now of felt for waterproofing, not of felt for roofing that is exposed to the air.

The writer has seen felt that had been laid in coal tar pitch; and, after 32 years service, it was as flexible as the day it was laid. This felt had been used to waterproof the outside of the masonry arch forming the roof of the Park Avenue Tunnel, N. Y. C. & H. R. Ry., built in 1872. The felt was laid in two layers and covered with 2 or 3 ft. of earth. Wherever it had been covered it was in perfect condition when taken out in 1904. Mr. A. B. Corthell, Terminal Engineer, New York Central Ry., New York City, has specimens of this old felt. As the process of making coal gas has not changed in the last 30 years, it is obvious that as good coal tar pitch is to be had to-day as ever. There are petroleum residues that are sold as pitch which are not of a durable nature, and such products have, perhaps, given a black eye to pitch in general.

Let us see what two layers of tar felt can be laid for:

	Two layers per sq. yd. cts.
2 sq. yds. tar felt at 2½ cts.	5
⅔ gal. asphalt at 12 cts.	8
Labor ($2 a day)	3
Total for 2 layers felt	14

This is equivalent to 7 cts. per sq. yd. of single layer. In the above estimate, 12% has been added to the price of the tar felt to allow for laps. The labor is assumed at a lower rate than would probably be paid in cities where labor unions control such work, but it is as high as would be paid outside of cities.

Cost of Waterproofing Batteries With Coal Tar and Sand.*—Coal tar and sand was used in waterproofing the superior crests of three batteries at Fort Mott, N. J. The tar was applied hot and was spread over the concrete surfaces with rubber squeegees and then sanded. Joints were filled with hot tar. A surplus of sand was put on and left for a few days and was then swept off. Two coats were put on over the traverses and one coat over the parapets. The total surface covered, two coats, was 14,700 sq. ft., and one coat, 19,600 sq. ft.; 21½ bbls. of coal tar were used, or about 1 bbl. per 2,279 sq. ft. The tar cost $4.25 per bbl. delivered, and the cost of the waterproofing, including materials and labor, was $0.0074 per sq. ft., one coat. In two of the batteries practically all percolation was stopped.

Cost of Waterproofing Bridge Floor, Pennsylvania Ry.†—Mr. A. L. Bowman is author of the following:

***Engineering-Contracting*, April 3, 1907.

†*Engineering-Contracting*, Nov. 4, 1908, p. 290.

Method of Applying Waterproofing.—First. The steel floor plate was thoroughly cleaned and painted with one coat of red lead and oil.

Second. A filler of mastic asphalt was placed along the webs of the girders.

Third. Five layers of Hydrex felt cemented together with Hydrex compound were then put on the floor plate and carried as far as possible up under the flashing angles, which were fastened along the webs and around the stiffeners and the ends of the girders. The felt was not cemented to the floor plate but was thoroughly cemented to the webs of the girders.

Fourth. A layer of brick laid flat was then placed on the felt in a hot layer of compound, the brick being laid lengthwise of the bridges.

Fifth. The joints between the brick were thoroughly poured with compound and the whole surface mopped with compound.

Sixth. The stone ballast ties and rails were then placed on the bridge (Fig. 11).

Labor and Time on Waterproofing After Steel Work Was Erected.

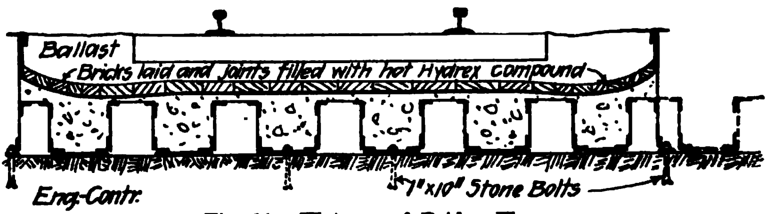


Fig. 11.—Waterproof Bridge Floor.

—The skilled and common laborer employed per square (100 sq. ft.) was as follows: Foreman, 1.66 hrs.; waterproofers, 11.71 hrs.; laborers, 7.75 hrs. The overtime to complete a floor of 750 sq. ft. was 1.4 days of 10 hrs. The best time for one track, 750 sq. ft., was one day of 10 hrs.

Cost.—The cost of waterproofing materials per square foot of floor surface was 20¾ cts. The cost of labor per square foot was 10¾ cts. Materials Per Square (100 sq. ft.).—Brick, 440; Hydrex compound, 41.2 gals.; Hydrex felt, 1.46 rolls (400 sq. ft. per roll).

Result.—The bridges are watertight with the exception of a few points immediately over columns.

During a severe storm the water leaks down to some extent, between the main and side walk girders. It seems impossible to keep these points absolutely tight.

The vibration and reflection of the girders break the bond of any material which is placed between the ends of the girders. From a close observation of these bridges it seems impossible to make the compound adhere to the steel for any length of time, due to the vibration of the steel work and the hardening of the material during cold weather.

It is necessary to protect the edges of the waterproofing along the girders from water running down behind after the waterproofing has broken loose. This was done by means of the flashing angles referred to above.

No attempt should be made to fit the brick along the web of brackets, the brick being simply shoved as tight as possible and then the openings poured with the compound. Afterward the opening under the flashing angles should be filled with concrete to keep the edges of the felt from curling over.

The felt was carried well over and down the back walls, drainage being had by putting the bridges on a grade and allowing the water to run behind the abutments, which were drained by pipes running through the abutments to the gutters.

Cost of Waterproofing, References.—For further data on this subject consult the index under "Waterproofing." See Chapter XXV, Methods and Cost of Waterproofing, in Gillette and Hill's "Concrete Construction."

Cost of Removing Efflorescence With Acid.—Efflorescence, or "whitewash," on a concrete bridge at Washington, D. C., was removed by using hydrochloric (muriatic) acid and common scrubbing brushes; 30 gals. of acid and 36 scrubbing brushes were used to clean 250 sq. yds. of concrete. The acid was diluted with 4 or 5 parts water to 1 of acid; and water constantly played with a hose on the concrete while being cleaned to prevent penetration of the acid. One house-front cleaner and 5 laborers were employed, and the total cost was $1.50, or 60 cts. per sq. yd. This high cost was due to the difficulty of cleaning the balustrades. It is thought that the cost of cleaning the spandrels and wing walls did not exceed 20 cts. per sq. yd. The cleaning was perfectly satisfactory. An experiment was made with wire brushes without acid, but the cost was $2.40 per sq. yd. The flour removed by the wire brushes was found by analysis to be silicate of lime. Acetic acid was tried in place of muriatic, but required more scrubbing.

For further data on cleaning with acid, see the section on Stone Masonry.* Consult the index under "Masonry, Cleaning."

Cost of Bush-Hammering Concrete.—Mr. C. R. Neher states that a concrete face can be bush-hammered by an ordinary laborer at the rate of 100 sq. ft. in 10 hrs., at a cost of 1½ cts. per sq. ft. The cost of forms saved by using rough lumber goes a long way toward covering the cost of bush-hammering. The front of the Dakota elevator in Buffalo, N. Y., was bush-hammered. Bush-hammering removes stains due to efflorescence.

Ransome says that bush-hammering concrete costs 1½ to 2½ cts. per sq. ft., wages of common laborers being 15 cts. per hr. The Ransome Concrete Mchy. Co., Dunellen, N. J., make a toothed ax especially designed for bush-hammering concrete.

The walls of the Pacific Borax Co. factory at Bayonne, N. J., were dressed by hand at the rate of 100 to 200 sq. ft. per day; but most of the dressing was done with a pneumatic hammer, with which a man was able to dress 300 to 600 sq. ft. per day.

At the Harvard Stadium I timed men working with pneumatic hammers, using a tool like an ice chopper with a sawtooth cutting blade. One man dressed a wall at the rate of 50 sq. ft. per hr., but I was told that 200 sq. ft. was a 10-hr. day's work. I am inclined to think, however, that much more than 200 sq. ft. a day could be averaged. Common laborers are used for this sort of work.

For the cost of operating pneumatic hammers, when gasoline is used for power consult the index under Pneumatic Hammer.

A common method of finishing concrete surfaces is to remove the forms before the concrete is very hard, say in 24 hrs., and scour the surface with a wire brush to as much as half the depth of the pebbles of gravel or stone. This can be done for 7 cts. per sq. ft.

The average cost of bush-hammering the concrete blocks for the Connecticut Ave. Bridge, at Washington, was 26 cts. per sq. ft. The work was done by stonecutters who received $4 per day, which partly accounts for the high cost. Moreover a very high grade of work was required. The cost ranged from 14 cts. per sq. ft. to 47 cts. per sq. ft., and is given in detail in Gillette and Hill's "Concrete Construction."

Cost of Excavating Concrete.—Mr. Ernest W. Shader gives the following. A hole was cut through a concrete dam 10 yrs. old at Ithaca, N. Y The concrete was crushed shale, and a mixture of natural and Portland cement had been used. The concrete was soft but tough. A pneumatic plug drill was used, and the concrete was chipped out with flat chisels 1½ ins. wide. A narrower chisel was not so good, and plug and feathering was impracticable because the drill would stick in the hole. (Perhaps a water jet would have overcome this difficulty.) Two Italian laborers alternated in holding the pneumatic machine, and they averaged exactly 1 lin. ft. of hole 5½ ft. diameter per 9-hr. day, for 16 days. The air pressure was 70 lbs. This is equivalent to 22½ cu. ft., or 0.83 cu. yd. per day by two men with a pneumatic machine.

A liberal supply of sharp chisels was provided. The chisel was sunk into the concrete until the blows of the hammer caused a piece to chip off. The time per chip ranged from a few seconds to 10 minutes. When the men become experienced they drove two or three chisels along a line and thus wedged off as much as ½ cu. ft. of concrete. This worked well when the lower part of the hole was advanced ahead of the upper part.

For comparison with the data above given, see Gillette and Hill's "Concrete Construction," p. 107, where it is stated that it took a quarryman 5 days to chip off 1 cu. yd. of concrete from the face of a concrete abutment that projected too far. Also see p. 653, etc., of the same book for methods and cost of blasting concrete.

For cost of excavating a concrete pavement base see the section on Roads and Pavements.

Cross References and References.—In other sections of this book will be found data on concrete costs, for which see the index under Concrete. The cost of quarrying and crushing stone for concrete

will be found in the section on Rock Excavation. In estimating the cost of forms the data in the section on Timberwork will be of aid.

The following books on concrete cover different parts of this great subject:

"Concrete Construction—Methods and Cost," by Gillette and Hill, is a 700-page treatise devoted solely to the methods and cost of concrete and reinforced concrete work of every variety. While intended primarily as a treatise for contractors and for engineers engaged in actual field work, it will aid the designer also if he aims to design and specify construction on which low bids will be assured. I cannot too often repeat the statement that no designer is thoroughly competent unless he has a thorough knowledge of every detail of actual cost.

"Concrete and Reinforced Concrete Construction," by Homer A. Reid, M. Am. Soc. C. E., is a 900-page treatise written primarily for the designing engineer and the engineering student, but it is full of illustrations of forms, arch centers, and text matter of value to the contractor also. There is, in my opinion, no single book that so well covers both theory of concrete design and practice of construction, as does this book, when the whole field of concrete is considered. The field, however, is so great that in addition to one such treatise covering the whole field, most engineers and contractors need special treatises on special branches, such as the one by Gillette and Hill, above mentioned, and such as the others mentioned below. Reid's work contains more than 700 drawings and half-tones. A statement of this number alone gives some idea of the wide scope of the work.

"Engineers' Pocketbook of Reinforced Concrete," by E. Lee Heidenreich, contains 374 pages of tables and data for the engineer who is designing reinforced concrete structures. I know of no book that is its equal for this purpose. The author is an experienced designer, indeed, one of the first American civil engineers to make reinforced concrete designing a specialty.

"Reinforced Concrete, A Manual of Practice," by Ernest McCullough, is a book which presents the subject of designing reinforced concrete in the simplest manner possible; also the principles of safe and good construction are set forth in an equally lucid manner. The author has had a very extensive experience in concrete work both as an engineer and as a contractor.

"Theory and Design of Reinforced Concrete Arches," by Arvid Reuterdahl, is self-explanatory in its title. The author's aim has been to present the theory in a perfectly complete form, leaving no gaps to be supplied by reference to other books.

"Concrete Bridges and Culverts," by H. G. Tyrrell, is a 272-page treatise in which the author presents the formulas to be used without giving the mathematical derivation, thus making it a very useful book for any engineer, other than the student of engineering. The author gives many tables of dimensions for standard railway and highway bridges and culverts, also tables of quantities and estimates of cost.

"Practical Cement Testing," by W. P. Taylor, is the work of a practical cement tester, and I think that in that respect it is unique among books or parts of books on cement testing. It covers the subject in its 330 pages.

"Concrete Inspection," by Charles S. Hill, is a pocket-size book of 186 pages, in which no extraneous matter is contained. It is a manual on cement inspection written by the author of the first American treatise on reinforced concrete construction, and an engineer who has a wider acquaintance with the literature of cement and concrete than anyone I have met. My close association with Mr. Hill in the production of our joint book, and in our editorial work, is the basis for the foregoing statement, in the breadth of which I may be unwittingly doing injustice to others who have attempted to keep pace with the literature on cement and concrete.

"Diagrams for Designing Reinforced Concrete Structures," by G. F. Dodge. The diagrams are plotted on logarithmic paper, and are so devised that results are read direct for any condition that occurs in ordinary practice.

Summary.—In this connection I may say that not since engineering began has there ever been a subject that has brought forth, in so short a time, so many articles, scientific papers, and books as have appeared on this subject of cement and concrete. This literature has had a profound influence upon the growth of the cement and concrete industry. Had it not been for the extensive literature on the subject, engineers would have been a generation longer in acquiring sufficient knowledge of concrete and its economic merits to lead them to the extensive use that concrete now enjoys. Authors of books and editors of, and contributors to, technical periodicals have been the educators who have made the use of concrete well nigh exclusive for some classes of construction, and a large factor in nearly every class that can be mentioned. In this process of education their work has been supplemented by that of intelligent manufacturers of cement and of concrete machinery, likewise to a degree never before witnessed in the technical advertising world. So, in concluding my references, I can do no better than to urge upon every engineer and contractor the importance of securing, and keeping up to date, a small library of the catalogs of manufacturers of cement and of concrete machinery, tools and appliances.

SECTION VII.

WATER-WORKS.

Definitions.—*Backfill,* the excavated earth that is put back into a trench.

Ball Joints.—A cast iron pipe with special ends that permit of deflection of the pipe line, after the lead has been poured, is said to have "ball joints" or "flexible joints."

Bell.—The flaring end of a cast iron pipe, as distinguished from the smaller end, or spigot, which fits into the bell.

Bell Holes.—After cast iron pipe are placed in a trench, it is customary to enlarge the trench somewhat by digging away the bottom and sides around the bells of the pipes, at each joint. The excavation thus made is called a bell hole.

Bend.—A short curved length of pipe. Bends are sold as "specials" at a price higher than for ordinary pipe. See Frye's "Civil Engineers' Pocketbook" for dimensions and weights of bends and other specials.

Brace.—A horizontal timber across a trench. Also an iron pipe with a telescopic end is called an "extensible brace."

Bracing.—The timber used to support the sides of a trench.

Branch.—A Y-shaped piece of pipe sold as a "special."

Calk.—To fill the joints of a pipe to prevent leakage. In cast iron pipe, yarn is first inserted; then lead is poured into the joint. The operation of driving the lead home is often called "calking," although the entire process of making a joint water tight is also termed calking.

Corporation Cock.—A cock or valve joining the main water pipe to the service pipe, so that the water may be shut off from any consumer.

Depreciation.—The loss of value due to lost life. If the straight line formula of depreciation is used, the annual depreciation is the reciprocal of the life in years; thus a life of 20 years gives a depreciation of 5% per annum Depreciation should not be confused with current repairs and renewals of parts.

Duty.—A term applied to pumping engines to express amount of work done. The Am. Soc. M. E. definition is number of foot pounds of work done by the expenditure of 1,000,000 B. T. U. (British thermal units). The duty therefore depends upon the character of engine employed.

Dynamic Head.—The actual head of water in a pipe plus the friction head.

Electrolysis.—The destruction of a metal due to chemical action developed by an electric current.

Faucet.—The flaring or "bell" end of a cast iron pipe.

Filter.—A "slow sand filter" consists of a large "filter bed" of sand, underlaid with gravel or broken stone, through which water passes and enters the drains that lead off the clear water. A "mechanical filter" (often called an "American filter"), consists of a small tank containing a bed of sand through which the water passes, after having been dosed with some coagulent, such as lime. The sand is cleaned at short intervals by reversing the current of water.

Flume.—A trough for carrying water; usually made of lumber.

Forebay.—The reservoir from which water passes immediately to a water wheel.

Friction Head.—The head of water necessary to overcome the friction developed by passing through a pipe.

Frost Box.—A box surrounding a waterpipe and containing some heat insulator, like mineral wool, excelsior or sawdust, to prevent the water from freezing.

Gallon.—The U. S. gallon contains 8 pints, or 4 quarts, or 231 cu. ins., or 0.13368 cu. ft., or 3.7855 litres, or 0.03175 liquid barrels. A cu. ft. contains 7.48052 (7½ nearly) gallons. A gallon of water, at 39.2° F., weighs 8.33888 (8⅓ nearly) lbs.; or 1 lb. of water = 0.12 gals. British Imperial gallon = 1.20032 U. S. gallons.

Gate.—A stop valve placed in water mains, usually at intervals of 300 to 900 ft., to shut off water from any section during repairs, etc.

Infiltration.—The flow of ground water into a well; or the flow of water through the ground, from a nearby lake or river, into a gallery.

Mains.—The system of large water pipes that supply the smaller laterals or service pipes.

Mineral wool, or slag wool, is fibrous slag, often used for packing around water pipes to prevent freezing.

Miners' Inch.—Usually the amount of water that will flow, in 24 hrs., through an opening 1 in. square in a plank 2 ins. thick, under a head of 6 ins. measured from the upper edge of the opening. Such an opening will discharge 11.625 gals. or 1.554 cu. ft. per minute, or 0.026 cu. ft. per sec. This is the Colorado miners' inch. The California miners' inch is 0.02 cu. ft. per second.

Oakum.—Material obtained by picking to pieces old hemp rope.

Packing.—Oakum with long fibres twisted into strands and used in filling pipe joints.

Pouring Clamp.—A device often used instead of the ordinary clay "roll" for holding in the molten lead used to form a joint in a cast iron pipe.

Puddle.—A mixture of gravel and clay, wet and compacted, and so deposited as to prevent leakage through more porous soil.

Ranger.—A long horizontal timber along the side of a trench, against which the "braces" abut.

Reducer.—A short funnel shaped section of pipe.

Roll.—A roll of clay placed temporarily around a pipe to retain the molten lead poured into the joint.

Runner.—Same as ranger.

Service Pipe.—A short lateral pipe of small diameter, usually of wrought iron or lead, extending from a "main" to a house, store, or the like.

Sheeting, or Sheathing.—Plank used to face the sides of a trench to prevent its caving in. When the planks are sharpened and driven, they are called sheet piles.

Shoring.—Braces used temporarily to support any structure while excavating near it. Also used to designate the braces and rangers in a trench, for which it is preferable to use the term bracing.

Skeleton Bracing.—A system of braces and rangers, without any sheeting; or merely a system of braces abutting against short lengths of plank.

Specials.—Bends, branches, tees, crosses, reducers, and all similar castings, other than the regular 12 ft. lengths of pipe, are called specials, and are sold (by the pound) at a higher price than the regular pipe.

Spigot End.—The small end of a cast iron pipe as distinguished from the bell end.

Stand Pipe.—A high, vertical pipe of large diameter holding a supply of water.

Ton.—Cast iron pipe is sold by the ton of 2,000 lbs. Pig iron is sold by the ton of 2,240 lbs.

Yarn.—Same as packing.

Cost of Complete Water Works Systems.—For purposes of rough preliminary estimates of cost, and more frequently for purposes of comparison and generalization, an engineer often wishes to know the approximate first cost of a complete waterworks system for a city or town of given size.

Table I is taken from a report by Mr. Paul Hansen, Assoc. M. Am. Soc. C. E., Assistant Engineer Ohio State Board of Health, and printed in *Engineering-Contracting,* Sept. 15, 1909. The author has the following to say about the table:

"The matter that most interests the taxpayer in connection with the installation of public water supplies is cost, and to this end I have prepared a table giving unit costs for construction and operation. These figures are necessarily very general, as they cover a wide range of conditions. They, however, are suggestive and give an approximate idea of expenditures involved."

Average Cost of Constructing and Operating Water Works in Massachusetts.—Mr. Freeman C. Coffin gives the following costs of constructing and operating 39 water works systems in Mass., for the year 1893. The systems were all owned by the municipalities, and in every case the water was pumped. Total cost of operation, including an allowance of 4% for interest on the first cost of the water works system, and 1½% for depreciation, averaged $115 per million gallons; the minimum cost being $65 in one city; and the maximum cost being $257. The average per capita cost was $2.58

TABLE 1.—AVERAGE COST OF CONSTRUCTION AND OPERATION OF PUBLIC WATER SUPPLIES.

Range of Population.	Average total cost of installation.	Average cost of per capita.	Maximum cost per capita.	Minimum cost per capita.	Average cost per person using.	Average total annual operating expenses.	Average annual operating expenses per capita.	Av. annual operating expenses per person using.	Minimum annual operating expenses per capita.	Max. annual operating expenses per person using.
*Under 500	8,557	20.02	43.50	6.20	48.84	508	1.10	2.05	0.09	4.38
‡500 to 1,000.......	17,948	22.12	38.60	9.15	35.18	1,071	1.28	1.99	.40	5.30
‡1,000 to 3,000......	32,442	18.31	32.50	14.00	29.90	1,677	1.52	2.36	.73	4.75
‡3,000 to 5,000	68,089	17.41	29.20	10.95	20.95	5,478	1.41	1.73	1.11	3.74
‡5,000 to 10,000	147,283	17.05	32.40	7.15	28.36	7,616	1.14	1.92	.75	3.08
‡10,000 to 20,000....	443,280	21.50	45.50	10.00	23.50	18,327	.86	1.03	.51	2.27
‡20,000 to 40,000....	667,200	18.30	22.70	8.71	22.90	28,760	.81	1.03	.55	1.41
‡Over 40,000	7,962,000	27.00	43.80	11.50	33.90	293,860	1.01	1.36	.78	2.08

*Average of three communities.
‡Average of ten communities.

per year; the minimum being $1.25; and the maximum being $5.62. The average daily per capita consumption was 62.3 gals.; the minimum being 23, and the maximum 227 gals. The water was pumped to an average height of 188 ft. dynamic head, which was about 10% greater than the static head. The coal consumption per million gallons was:

	Tons.
Minimum	0.75
Average	1.67
Maximum	7.00

The number of gallons pumped 1 ft. high (dynamic head) per pound of coal was:

Minimum	8,040
Average	56,344
Maximum	132,550

These cities may be divided into three groups: Group I, 22 cities under 15,000 population, and averaging 5,880 population (or consumers) on the pipe lines; Group II, 8 cities, 15,000 to 26,000 population, with an average of 21,250 on the pipe lines; and Group III, 8 cities, 31,500 to 85,000 population, with an average of 56,000 on the pipe lines.

The first cost of the water systems and the cost of operation, etc., for each of these three groups was as follows:

Group I.—Twenty-two cities, total population 129,300, on the pipe lines, consume 2,556,300,000 gals. per year, or 55 gals. per capita per day. The pumping plants consumed 6,500 tons of coal per year, or 2½ tons per million gallons. There were 472 miles of pipe line, and the cost of the water systems was $4,720,000, or $10,000 per mile of pipe line, including the cost of the pumping plants. There were 3,800 hydrants and 22,000 services; or 8 hydrants and 46 services per mile of pipe line. The cost of the water systems was $365 per capita, or $1,850 per million gallons annually consumed. The annual cost of operation, etc., was as follows:

	Total	Per Million Gals.
Pump station expense	$ 49,200	19.30
Other expense of maintenance and operation	58,400	22.80
Interest, 4% on $4,720,000	188,800	74.00
Depreciation, 1½% on $4,720,000	70,800	27.70
Total	$367,200	$143.80

In this group there were two cities where the cost was $85 per million gallons, and there was one where the cost was $252.

Group II.—Eight cities, total population 170,000, on the pipe lines, consumed 4,330,000,000 gals. per year, or 70 gals. per capita per day. The pumping plants consumed 5,339 tons of coal per year, or 1.23 tons per million gals. There were 425 miles of pipe line, and the cost of the water systems was $6,200,000, or $14,600 per mile of pipe line. There were 3,270 hydrants and 24,944 services, or nearly 8 hydrants and 60 services per mile of pipe line. The cost of the water systems was nearly $370 per capita, or $1,430

per million gallons annually consumed. The annual cost of operation was as follows:

	Total.	Per Million Gals.
Pump station expense	$ 62,400	$ 14.35
Other expenses	90,100	20.72
Interest 4% on $6,200,000	248,000	57.04
Depreciation, 1½% on $6,200,000	93,000	21.39
Total	$493,500	$113.50

Group III.—Eight cities, total population 448,500, on the pipe lines, consumed 10,750,000,000 gals. per year, or 66 gals. per capita per day. The pumping plants consumed 10,835 tons of coal, or 1 ton per million gallons. There were 675 miles of pipe line, and the cost of the water systems was $16,300,000, or $24.100 per mile of pipe line. There were 5,400 hydrants and 57,848 services, or 8 hydrant and 86 services per mile of pipe line. The cost of the water systems was $363 per capita, or $1,516 per million gallons annually consumed. The annual cost of operation was as follows:

	Total.	Per Million Gals.
Pump station expense	$ 101,700	$ 9.40
Other expenses	203,800	18.75
Interest, 4%	651,900	61.12
Depreciation, 1½%	244,500	22.57
Total	$1,201,400	$111.84

In this group there was one city of 44,000 population where the cost was only $65 per million gallons, distributed thus:

	Total.	Per Million Gals.
Pump station expense	$ 13,466	$ 7.43
Other expenses	17,656	9.80
Interest, 4%	63,605	35.12
Depreciation, 1½%	23,851	13.14
Total	$118,578	$65.49

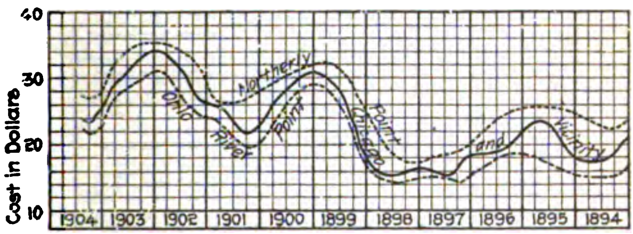
The coal consumption was 0.7 ton per million gallons, the dynamic head being 130 ft. (static head, 125 ft.). The cost of the system was $361 per capita, or $25,000 per mile of pipe line, or $880 per million gals. consumed annually. This low first cost of plant per million gallons annually consumed is not due to superior design of plant, but to the large consumption of water, which was 112 gals. per capita per day. The per capita cost of water was $2.69 per annum, which is above the average cost of this group.

Prices of Cast Iron Pipe.—Figure 1 shows the prices paid for cast iron pipe in cities and towns of the Central West, centering about Chicago, according to data collected by J. W. Alvord from various pipe contracts.

The prices of pipe are per ton of 2,000 lbs., and are from $7 to $10 above the prices for pig iron per ton of 2,000 lbs. in the same localities at the same time.

Prices of Cast Iron for Thirteen Years in Chicago.—The average cost of cast iron pipe per ton since 1894 to the Water Pipe Extension Division of the City of Chicago, Ill., has been as follows:

	Cost Per Ton.	Per Cent Variation in Cost.
1895	$26.00	100
1896	23.00	88.4
1897	19.00	73.0
1898	25.00	96.1
1899	25.50	98.0
1900	25.50	98.0
1901	23.50	90.4
1902	28.00	107.7
1903	33.00	126.9
1904	30.00	115.4
1905	27.50	105.8
1906	30.00	115.4
1907	37.20	143.1



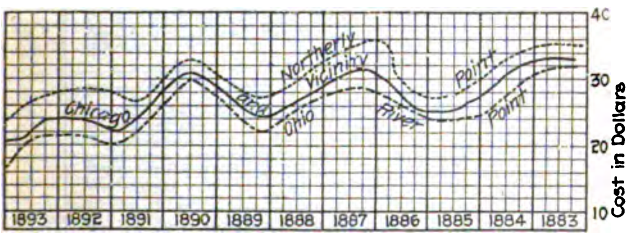


Fig. 1.—Prices of Cast Iron Pipe.

Weight of Cast Iron Pipe.—Pipe from 3 ins. to 60 ins. diameter is cast in 12-ft. lengths, that is in lengths that require 440 pipe lengths to lay a mile of pipe line; 1½-in. and 2-in. pipes are not often used, but when used are cast in shorter lengths.

Table Ia gives the approximate weights of cast iron pipes. It is customary to paint the weight of each pipe inside the pipe. As variations in single pipes of 5% from the listed weight are common, it is well to specify the maximum average variation allowable.

TABLE Ia.—WEIGHT OF CAST IRON PIPE.

Inside Diam. of Pipe, in inches.	Head, 100 ft. Pressure, 43 lbs. Thickness, Ins.	Weight, lbs. per Foot.	Weight, lbs. per Length.	Head, 200 ft. Pressure, 86 lbs. Thickness, Ins.	Weight, lbs. per Foot.	Weight, lbs. per Length.	Head, 300 ft. Pressure, 130 lbs. Thickness, Ins.	Weight, lbs. per Foot.	Weight, lbs. per Length.	Head, 400 ft. Pressure, 173 lbs. Thickness, Ins.	Weight, lbs. per Foot.	Weight, lbs. per Length.	Lead per Joint, Lbs.	Hemp per joint, Lbs.	Inside Diam. of Pipe, in inches.
3	.38	13.9	167	.42	15.4	185	.45	16.7	200	.45	16.7	200	4.4	.18	3
4	.40	19.2	230	.42	20.3	243	.45	21.7	260	.47	22.1	265	5.5	.21	4
5	.42	24.6	295	.45	26.3	315	.48	28.2	338	.51	29.6	355	6.8	.27	5
6	.43	30.4	364	.47	32.8	393	.51	35.5	426	.54	37.1	445	8.0	.31	6
8	.47	42.8	513	.51	47.3	567	.56	52.0	624	.61	55.4	665	11.5	.44	8
10	.50	57.1	685	.56	63.8	765	.62	71.0	852	.68	76.7	920	14.5	.53	10
12	.53	72.5	870	.60	82.1	985	.68	92.5	1110	.75	100.8	1210	18.0	.61	12
14	.56	89.5	1074	.65	102.4	1229	.73	116.6	1399	.82	128.3	1540	21.5	.81	14
16	.60	107.8	1293	.69	124.7	1496	.79	143.6	1723	.89	158.3	1900	24.0	.94	16
18	.63	127.7	1532	.74	149.0	1788	.85	172.1	2065	.96	191.7	2300	27.0	1.00	18
20	.66	149.0	1788	.78	175.3	2104	.91	203.7	2444	1.03	228.3	2740	31.5	1.25	20
24	.75	200.6	2407	.87	233.6	2803	1.02	274.9	3299	1.16	306.7	3680	37.0	1.50	24
30	.87	290.2	3482	1.01	356.6	4027	1.19	398.6	4783	1.37	451.7	5420	51.0	2.06	30
36	.98	391.6	4699	1.14	455.0	5460	1.30	545.3	6543	1.58	624.2	7490	75.0	3.00	36
40	1.09	483.9	5807	1.23	543.8	6525	1.48	654.8	7858	1.72	754.2	9050	85.0	3.37	40
42	1.10	512.3	6147	1.28	591.7	7100	1.54	713.6	8563	1.79	824.2	9890	90.0	3.62	42
48	1.25	665.2	7982	1.41	745.5	8946	1.71	904.8	10857	1.99	1045.8	12550	110.0	4.37	48
60	1.40	916.7	11000	1.68	1105.0	13260	2.05	1336.7	16040	2.41	1580.8	18970	150.0	6.25	60

Lead Required for Joints.—Billings states that the theoretical amount of lead required for joints in pipe used in Boston was given by the formula, $p = 2d$, in which p = lbs. of lead per joint, and d = diameter of pipe in inches. Actually, however, the following amounts were used:

Size of pipe. ins.	Actual lbs. lead. per joint.	Theoretical lbs. lead. per joint.	No. of ft. pipe laid	Lbs. lead per ft. of pipe.
6	7.7	12	3,112	0.64
8	9.1	16	1,997	0.76
16	21.0	32	550	1.75
16	23.7	32	10,000	1.97

In the following examples of cost, data will be found as to the amount of lead used in different cases.

Items of Cost of Pipe Laying and Materials.—The expression, "cost of laying pipe," is usually used to include all labor costs of trenching, distributing and placing pipe, calking and backfilling. Sometimes the cost of lead and yarn is included as "cost of laying." Every carefully kept record of cost should contain the following items of cost, expressed in terms of the lin. ft. of pipe of stated size and weight:

Materials:
- Cast iron pipe.
- Lead for joints.
- Yarn.
- Wood blocks, if any.

Labor:
- Labor loading wagons from cars.
- Teams hauling.
- Labor unloading.
- Labor distributing along the trench.
- Teams trenching.
- Labor excavating trench.
- Labor digging bell holes.
- Labor backfilling holes.
- Teams backfilling holes.
- Labor pumping.
- Labor placing pipe in trench.
- Labor placing yarn in joints.
- Labor melting and pouring lead.
- Labor calking joints.
- Foremen, water boy, watchman.
- General superintendence, timekeeping and office expense.

Supplies and Tools:
- Timber, etc., for bracing.
- Fuel.
- Repairs and depreciation of tools.
- Explosives.

Miscellaneous:
- Pay roll insurance (accident).
- Insurance of public (accident).
- Premium on contractors' bond.

While the lineal foot is the common unit used in expressing the cost of a pipe line, it should be remembered that the principle item of labor cost is trenching, which is better reduced to the cubic yard of excavation as the unit. The cost of loading and hauling the pipe should also be reduced to the ton and the ton-mile, as the best units for comparing costs.

Tho material and labor cost of "specials," valves, hydrants, meters, service pipes, etc., should be recorded separately, and not lumped in with the cost of the main pipe line.

The length of the job should be recorded, for usually there is a certain amount of time required to organize the gang of men, to weed out incompetents, etc. Then, too, there is generally a "fixed expense" (independent of the length of the job), involved in getting the materials, plant and men onto the job, ready for work. The effect of these items is well shown in some cost records given on page 663.

The cost of removing an existing pavement and relaying the pavement should be recorded as a separate item, expressing it in terms of the square yard of pavement. See the section on Roads, Pavements and Walks.

Cost of Loading and Hauling Cast Iron Pipe.—Three men assisted by a driver averaged 5 lengths of 12-in. pipe loaded from a flat car onto a wagon in 12 mins. Planks were laid from the car to the wagon and the pipe was rolled down the plank runway. This same gang would unload a wagon in 6 mins. As each length of pipe weighed nearly ½ short ton, the wagon load was 2½ tons. It, therefore, cost 5 cts. per ton to load and 2½ cts. per ton to unload the wagons, wages of men being 15 cts. per hr.; but this does not include the lost time of the two horses during loading and unloading, which is equivalent to about 2 cts. per ton. The total fixed cost of loading and unloading was 10 cts. per ton, including team time, to which must be added the hauling costs of 12 cts. per ton per mile, where 2½ tons are the load (wages of team and driver 35 cts. per hr.), and the team returns empty. Good, hard, level roads are required for so large a load. If the haul is short and this loading gang of 3 men walks along with the wagon, the cost of hauling becomes 25 cts. per ton mile, instead of 10 cts.

Pipe should never be shipped in hopper-bottom cars, for the difficulty of unloading adds very much to the cost. I have had a gang of 6 men who unloaded only 75 lengths of 12-in. pipe in 10 hrs. from a hopper gondola, into wagons. Each length weighed 800 lbs., making 30 tons the day's work, at 30 cts. per ton. This work was by hand, no derrick being available.

Water Pipe Trenches.—Trenches for water pipes in the northern part of America are usually 5 ft. deep from the surface of the street to the axis of the pipe. In the South, trenches are only 3 ft. deep. Water-pipe trenches are usually dug not less than 18 to 24 ins. wider than the inside diameter of the pipe; and just before the pipes are laid a gang of men enlarges and deepens the trench for a short space where each pipe joint is to come; this is called digging the "bell-holes." The bell-holes enable the yarners

and calkers to make the joints properly. It is usually not necessary to brace the sides of a trench that is only 5 or 6 ft. deep, to prevent caving in. The shallow depth and the absence of bracing make waterpipe trenching cheaper than sewer trenching.

The backfilling is often done entirely by hand, the earth being rammed in thin layers. This is far more expensive than backfilling with a drag scraper pulled by horses, as is shown in the examples that follow.

The reader is referred to the Sewer Section for additional data on trench work.

There are several excellent makes of trench excavating machines on the market. Where enough work exists to warrant the purchase of one of these machines, and where neither boulders nor numerous buried pipe lines occur, trenching with these machines is far cheaper than hand work.

The cost of excavating a water pipe trench with one make of trench machine is given in the next paragraph. Costs of similar work in sewer trenching and in tile ditching will be found in the Sewer Section and in the Miscellaneous Section. See also the sections on Earth Excavation and Rock Excavation. All data relating to trenching will be found by consulting the index under Trenching.

Cost of Digging a 36-Mile Trench With a Buckeye Traction Ditcher.*—A wooden pipe line is used to bring the water from the mountains for the new water system of the city of Greeley, Colo. This line is 36 miles long. Of this distance 2,000 ft. was in rock. This part was excavated by hand and the rest of the trench was excavated by a Buckeye traction ditcher, manufactured by the Buckeye Traction Ditcher Co. of Findlay, O.

For eight miles the trench ran through a stratum of gravel, containing many stones; some of the gravel was also cemented together. The material in the rest of the trench was clay, rather hard, but the machine dug it with great ease. In a ten hour day the machine in the gravel would dig from 600 to 1,000 ft., while in the clay as much as 2,500 ft. of trench was dug in 10 hours. The style of machine used is shown in the accompanying cut. It was a 28-in. by 7½-ft. drainage machine. Such a machine is designed for digging ditches for draining land, the type meant for contractors' use in heavy trench work being more substantially constructed and of greater weight. This machine weighed 17 tons, while a contractor's machine of the same size would weigh 24 tons and cost $1,300 more than this machine did when new.

The Buckeye ditcher, Fig. 2, being a traction engine as well as a ditch digger, moves along automatically as it digs the trench. It throws the excavated material into the conveyor belt alongside of the wheel, and this belt dumps the earth clear of the ditch, so that the earth does not interfere with the pipe laying and other work that may have to be done in the trench. The bottom of the trench is rounded by the buckets on the wheel, so that pipe laid in the

**Engineering-Contracting,* Feb. 12, 1908.

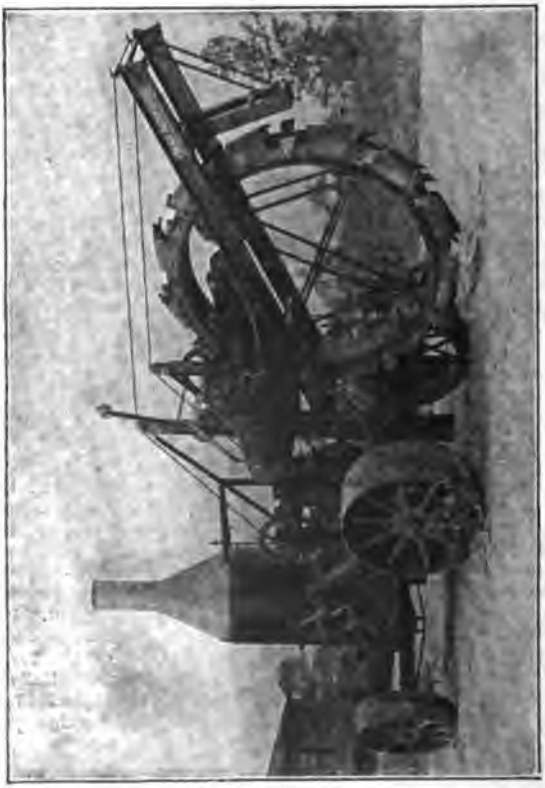


Fig. 2.—Trench Digger.

trench does not roll from side to side. Two men can operate the machine under favorable circumstances. In backfilling the material can be pushed into the trench by the ditcher, used as a traction engine, by fastening a plank to an outrigger, which acts in a manner similar to a snow plow. A drag scraper can also be used in backfilling. The fact that the machine pulverizes the earth to a great extent in digging makes the backfilling easier than when the earth is in chunks.

The trench dug at Greeley was throughout its entire length 30 ins. wide and 4 ft. deep. This meant that a lineal foot of trench contained 10 cu. ft. of earth or .37 cu. yd. As the total length of trench dug by the machine was 188,080 lin. ft., in all 69,659 cu. yds. of earth were excavated. All the work of excavating with the machine was done by 4 men. The man running the ditcher was paid $5 per day, and the other three $3 per day of 10 hours. The men worked 300 days. The ditcher when new cost $5,200, but this machine had been used before, and was bought by the contractors as a second hand machine.

In the summary of cost given below we have allowed $6 per day for repairs and renewals and interest and depreciation, which is 30 per cent per annum on the original cost of the machine. We are informed by the contractors that this machine used on an average of 1 ton of coal per day, the coal costing $5 per ton.

The cost of digging the trench was:

300 days, engineer	$1,500.00
900 days, helpers	2,700.00
300 tons coal	1,500.00
300 days, plant charges at $6	1,800.00
Total	$7,500.00

This cost, as will be seen, does not include any general expenses, the cost of getting the machine to and from the job or the cost of backfilling.

The cost of water used for one of these machines is nominal, as they use about 1 gallon of water for each pound of coal.

The cost per lineal foot of trench for each item was:

Engineer	$0.008
Helpers	0.014
Coal	0.008
Plant	0.010
Total	$0.040

The average number of lineal feet dug per day was 627, although, as previously stated, much more than this was done when the ditcher was actually working. The average given includes all lost time. This machine is speeded to dig 3 lin. ft. of trench 3 ft. deep per minute, and 2 lin. ft. of 4½-ft. trench per minute. In good material better speed than this was obtained, but naturally it could not be made continuously. The same thing may be said in regard to the yardage excavated. On some days more than 900 cu. yds. of material were excavated, but the average yardage per day for the entire job was 232.

The cost per cubic yard for the work was as follows:

Engineer	$0.021
Helpers	0.040
Coal	0.021
Plant	0.025
Total	$0.107

This is low cost for trench excavation, even for a ditch only 4½ ft. deep.

The contractors for this work are the Jacobsen-Bade Co. of Portland, Oregon.

Trenching in Quicksand, Using a Helm Trench Machine.*—The work comprised the placing of a 20-in. main in trench from 5 ft. to 13½ ft. deep connecting two reservoirs at Madison, Wis. The conditions were quite different. The new reservoir was located in a low marshy soil with its bottom 5 ft. below the surface, the bottom of the old reservoir was 16 ft. below the surface. The main connecting the two reservoirs was 1,068 ft. long.

Beginning at a depth of 5 ft. at the new reservoir, the trench curving to the rise in the ground surface increased to a depth of 10 ft., at 425 ft. from the starting point. Here an old lake bed of 6½ ft. of quicksand and a stream of running water was encountered. This quicksand and water had to be contended with to the end of the pipe line and with an increasing depth of trench to 13½ ft. Besides the unstable soil there were several interfering pipe lines.

Work was begun with an ordinary derrick, but this was soon abandoned for a four-leg saw-horse derrick with a traveler. For the more difficult portions of the work still another derrick or trench machine, that shown in Fig. 3, was devised. This machine was used for handling excavation and pipe. It was 36 ft. long, with four buckets and two crank gears to raise and lower them. The same apparatus was used to handle the pipe, a 12-ft. length of which weighed a ton. These men did the excavating and lowered the pipe. The trench had to be sheeted to from 2 to 3 ft. below the bottom with 3-in. plank braced every 3 ft. The rate of progress was one length of pipe laid every 1½ days. Toward the end of the saw-horse derrick work it took three days to lay a length of pipe and by the ordinary methods it is stated that the same work would have required seven days. The machine also reduced the excavating force by 15 men. Mr. John B. Heim, superintendent, under whose direction the work was done, estimates the saving per length of pipe due to the machine $168.50, or for 23 lengths of pipe laid at $3,775.50. He writes further regarding the work as follows:

"We had to pump day and night and dare not pump any faster than to keep the water down for fear of drawing the quicksand back of the sheeting into our trench and undermining the dirt.

"The buckets were on a swivel and held by a spring, and were emptied on the pipe as we moved along. It took us over three

*Engineering-Contracting, Sept. 29, 19[illegible]

months to lay 645 ft. of main with from fourteen to eighteen men at times used to trim the street after us. We did not interfere with the street or street railway traffic. It was a macadamized street, and, in spite of the treacherous soil working in at the back of the sheathing, we left the street in a passable condition for the winter. There was only slight settling here and there in the spring. During the whole siege we had to contend with the water, gas and sewer laterals, and towards the end we had to cut diagonally across the street. Here we had to go under a 6-in., an 8-in. and a 12-in. water main, a 16-in. suction-main from the artesian wells, a gas main, two sewer mains and the street railway tracks, at a depth

Fig. 3.—Trench Machine.

of 13½ ft., with 6½ ft. of quicksand and a continuous stream of water to fight. Our trenching machinery did away with building platforms to bring the soil to the top, saving us at least fifteen men to do this labor, besides requiring only three men to lower the pipe, so easy to handle, blocked to grade, as our fall is only 1 ft. in a distance of 1,068 ft., towards the old storage reservoir by gravity. With the saw-horse derrick, towards the end, when our depth increased, it required three days to lay a pipe, so that we gained, besides the fifteen men, one and a half days for each length, not figuring at an increased depth to lay the same. Where we encountered so many pipes going across the street and at times the different laterals, we had to lower the pipe at a slant and at times perpendicular. The work was accomplished with ease. I do not

see how we could have got along without this machine, and without the machine we could not have accomplished the work before the cold weather set in, besides working at a greater expense."

The trench machine illustrated was designed by Mr. John B. Heim, superintendent Department of Water Works, Madison, Wis., who gives the cost of the main as follows.

Pipe, specials, valves, lead, hemp, coke, etc., with freight and cartage	$ 5,800
Lumber, machinery, braces, blocks, pumps, etc.	1,676
Labor	4,870
Total	$12,346

This gives a cost per foot of $12,346 ÷ 1,060 = $11.647.

Cost of Trenching at Corning, N. Y.—A trench for a 10-in. water pipe was excavated 2½ ft. wide × 5 ft. deep × 1,500 ft. long = 600 cu. yds. in 4½ days by 24 men, or at the rate of 6 cu. yds. per man per 10-hr. day, equivalent to 11 cts. a running foot or 25 cts. a cu. yd. The backfilling was done in 3 days by 2 men and 1 horse with driver, using a drag scraper and a short length of rope so that the horse worked on one side of the trench while the two men handled the scraper on the opposite side, pulling the scraper directly across the pile of earth. In this way the backfilling was made at a cost of 1.1 cts. per lin. ft. or 2½ cts. per cu. yd., there being no ramming of the backfill required. This is a remarkably low cost for backfilling, and one not ordinarily to be counted upon. The material was a loamy sand and gravel.

At Rochester, N. Y., with the size of trench and kind of material practically the same as above:

1 man excavated 8 cu. yds. a day at cost of 19 cts. per cu. yd.

1 man backfilled 16 cu. yds. a day at cost of 9 cts. per cu. yd.

Total cost of excavation and backfill, 28 cts. per cu. yd.

The cost of laying the 10-in. pipe was as follows, 800 ft. being laid per 10-hr. day by the gang:

3 laborers digging bell holes at $1.50	$4.50
3 laborers laying pipe at $1.50	4.50
1 man hemping joints at $2.50	2.50
2 men pouring lead at $2.50	5.00
3 men calking joints at $2.50	7.50
Total, 800 ft. at 3 cts.	$24.00

This does not include trenching nor hauling and distributing pipe.

Cost of Trenching, Great Falls, Mont.—The Great Falls (Montana) Water Co. excavated 25,500 cu. yds. of earth, 1,900 cu. yds. of loose rock, and 1,500 cu. yds. of solid rock, in trenching for a 6-in. water pipe. The work was done by company labor (not by contract), wages being $2.25 for laborers, and the cost was 34 cts. per cu. yd. for excavation and 3½ cts. more per cu. yd. for backfilling and tamping. If wages had been $1.50 a day the cost would have been 23 cts. per cu. yd. for excavation and 2½ cts. per cu. yd. for backfilling.

Cost of Trenching, Astoria, Ore.—Mr. A. L. Adams states that in trenching for the Astoria (Oregon) Waterworks, in 1896, the

first contracter averaged only 7 to 8 cu. yds. per man per day. Later on another contractor, even in the rainy season, averaged nearly 10 cu. yds. per man per 10-hr. day of trenching (including backfilling), at a cost (including foreman) of 17¼ cts. per cu. yd., wages being $1.70 a day. The material was yellow clay dug with mattocks and shovels.

Cost of Trenching, Hilburn, N. Y.—Mr. W. C. Foster gives the following data on 17,000 ft. of trenching for water pipe at Hilburn, N. Y. The trench was 4 ft. deep, for 4-in. to 8-in. pipe. The digging was hard, the banks being full of cobbles and frequently caved in. The streets were not paved. The cost of trenching and backfilling was 10.1 cts. per lin. ft., wages being $1.35 for laborers and $3 for foremen.

Cost of Pipe Laying, Providence, R. I.—Mr. E. B. Weston, Engineer Water Department, Providence, R. I., gives the following tables based upon many miles of trench work done prior to 1890:

EASY DIGGING SAND.

Size of pipe, ins...	4.	6.	8.	10.	12.	16.	20.
1. Trenching*	.0422	.0518	.0611	.0707	.0798	.1445	.2088
2. Laying	.0129	.0162	.0191	.0219	.0249	.0370	.0497
3. Foreman	.0130	.0158	.0188	.0216	.0244	.0303	.0360
4. Tools, etc.	.0041	.0050	.0059	.0069	.0078	.0134	.0191
5. Calking	0106	.0107	.0108	.0111	.0118	.0159	.0301
6. Lead, 5 cts. lb..	.0224	.0320	.0431	.0553	.0683	.0950	.1203
7. Teams	.0070	.0090	.0115	.0136	.0160	.0203	.0216
8. Carting	.0078	.0149	.0208	.0275	.0346	.0518	.0746
9. Total	.1200	.1554	.1911	.2286	.2676	.4082	.5602

MEDIUM DIGGING, GRAVEL, ETC.

Size of pipe, ins...	4.	6.	8.	10.	12.	16.	20.	24.
1. Trenching*	.0597	.0697	.0790	.0883	.0974	.1700	.2400	.3019
2. Laying	.0189	.0220	.0249	.0279	.0307	.0440	.0577	.0639
3. Foreman	.0180	.0206	.0234	.0265	.0294	.0350	.0373	.0396
4. Tools, etc.	.0056	.0065	.0075	.0084	.0093	.0154	.0214	.0602
5. Calking	.0106	.0107	.0108	.0111	.0118	.0159	.0301	.0757
6. Lead, 5 cts. lb...	.0224	.0320	.0431	.0553	.0683	.0950	.1203	.1600
7. Teams	.0070	.0090	.0115	.0136	.0160	.0203	.0216	.0228
8. Carting	.0078	.0149	.0208	.0275	.0346	.0518	.0746	.1317
9. Total	.1500	.1854	.2210	.2586	.2975	.4474	.6030	.8630

*Including backfilling, and in all cases the depth of the trench was such that the center of the pipe was 4 ft. 8 ins. below ground surface.

HARD DIGGING, HARD OR MOIST CLAY.

Size of pipe, ins...	4.	6.	8.	10.	12.	16.	20.
1. Trenching*	.0860	.0959	.1053	.1147	.1300	.2261	.3264
2. Laying	.0271	.0303	.0333	.0362	.0411	.0530	.0669
3. Foreman	.0260	.0286	.0314	.0343	.0372	.0428	.0452
4. Tools, etc.	.0081	.0090	.0099	.0109	.0118	.0201	.0283
5. Calking	.0106	.0107	.0108	.0111	.0118	.0159	.0301
6. Lead, 5 cts. lb..	.0224	.0320	.0431	.0553	.0683	.0950	.1203
7. Teams	.0070	.0090	.0115	.0136	.0160	.0203	.0216
8. Carting	.0078	.0149	.0208	.0275	.0346	.0513	.0746
9. Total	.1950	.2304	.2661	.3036	.3508	.5250	.7134

*Including backfilling, and in all cases the depth of the trench was such that the center of the pipe was 4 ft. 8 ins. below ground surface.

Wages in all cases above were $1.50 a day for laborers trenching and laying, $3 a day for foreman, $2.25 for calkers, and $2.25 for teams which probably refers to team without driver. Carting was in all cases $1 a ton. Allowance for tools, item 4, was made on a basis of 7.2% of items 1 and 2.

Tap and stop		Lead service pipe per lin. ft.		
Diam. in ins.	Tap, stop, etc. including tapping.	Diam. in ins.	Weight in lbs.	Cost of pipe trenching laying, etc.
3/8	$6.00	1/2	3.00	$0.34
1/2	6.23	5/8	4.00	.40
5/8	6.81	3/4	4.75	.45
3/4	8.67	1	6.00	.52
1	10.71	1 1/4	9.00	.70
...	.....	1 1/2	10.00	.76

In the above, lead pipe was assumed at 6 cts. per lb.; labor of trenching and laying, 16 cts. per ft.

Short lengths, 15 to 50 ft., of 6-in. pipe cost 34 cts. per ft. in easy digging to 45 cts. in hard digging for excavation, laying and backfilling, wages being as above stated.

The trench for a 24-in. pipe, 19,416 ft. long and 6.6 ft. deep cost 32 cts. per cu. yd. for excavation and backfill, with wages at $1.50 a day.

A 48-in. main was laid for $1.65 per ft. including digging, laying, calking and backfilling.

A 16-in. pipe, 374 ft. long passed under two railway tracks, and the cost of trenching, laying and backfilling was 50 cts. per ft.

An 8-in. pipe was laid across a bridge, and the cost of boxing, laying pipe, etc., was $1.32 per ft., while for a 12-in. pipe the cost was $1.50 per ft.

Trenches were ordinarily 2 ft. wider than the pipe and 5 ft. plus half the diameter of the pipe deep. Such trenches were dug, the pipe laid and backfilling made at the following rate per laborer engaged:

6-in	pipe,	easy earth	21.0 lin. ft. per day
6-in.	"	medium earth	17.2 " "
6-in.	"	hard earth	10.3 " "
8-in.	"	easy earth	19.3 " "
12-in.	"	medium earth	13.4 " "
20-in.	"	easy earth	9.0 " "
24-in.	"	medium earth	4.4 " "

Earth excavation in trenches where digging is easy costs 20 cts. per cu. yd.; rock excavation averages $2 per cu. yd. and runs as high as $3, wages being $1.50 a day for labor.

Cost of Laying 107,877 Feet of Water Mains at Cleveland, O.*— During 1907 the Pipe Laying Department of the Division of Water Works of Cleveland, O., laid 107,877 ft. of watermains, the sizes of pipe and lengths laid being as follows:

**Engineering-Contracting,* Nov. 4, 1908.

30-in.	5,330 ft.
24-in.	11,164 ft.
20-in.	1,665 ft.
12-in.	17,362 ft.
10-in.	1,181 ft.
8-in.	15,099 ft.
6-in.	53,415 ft.
4-in.	439 ft.
3-in.	2,222 ft.

Table II, prepared by M. E. Bemis, superintendent of water works, shows the unit cost of laying these watermains.

Mr. Bemis states that the costs were rather high, owing to the unusually high prices of materials prevailing during the year. The prices for materials at Cleveland, during 1907 were as follows:

	Per ton.
All sizes of cast iron pipe, delivered on streets, for the first half of 1907	$36.25
For the second half of 1907	36.00
Miscellaneous castings and special castings, from 3-in. to 16-in., inclusive, first half of 1907	54.00
Miscellaneous castings over 16-in., first half of 1907	60.00
Miscellaneous castings, second half 1907	59.90
Special castings, from 3-in. to 16-in., inclusive, second half 1907	65.00
Special castings, over 16-in., second half 1907	75.00

	Each.
3-in. valves	$ 6.53
4-in. valves	7.63
6-in. valves	12.60
8-in. valves	18.90
10-in. valves	26.25
12-in. valves	34.50
16-in. valves	66.15
20-in. valves	134.25
24-in. valves	217.50
3-in. hydrants	20.00
4-in. hydrants	27.75
6-in. hydrants	46.25
Pig lead, first half of 1907	$123.30 per ton f. o. b. point of shipment
Pig lead, second half of 1907	$101.00 per ton f. o. b. cars at Cleveland
Packing	4¾c per lb.

The wages paid for labor were as follows:

	Per hour.
Foreman	$0.42
Assistant foreman	0.33
Calkers	0.27½
Labor	0.22
Team	0.50

Cost of Water Pipes Laid at Boston.—Mr. C. M. Saville gives the following data relative to 62 miles of pipe work done by contract for the city of Boston: The costs are averages of the actual costs under 21 contracts, from 1896 to 1903. As a general rule the

TABLE II, SHOWING THE COST PER FOOT OF 107,877 FT. WATERMAIN LAID DURING 1907.

	30-in.* per ft.	24-in.* per ft.	20-in.* per ft.	12-in. per ft.	10-in. per ft.	8-in. per ft.	6-in. per ft.	4-in. per ft.	3-in. per ft.
Pipe and specials	$5.486	$4.234	$3.565	$1.649	$1.402	$ .958	$ .708	$ .463	$ .329
Valves	.139	.167	.281	.126	.203	.070	.054	.062	.021
Hydrants	.000	.000	.000	.103	.268	.107	.082	.069	.000
Lead	.354	.312	.222	.141	.165	.087	.064	.050	.025
Miscel. material†	.090	.106	.084	.167	.011	.026	.014	.039	.002
Total material	$6.069	$4.819	$4.152	$2.186	$2.049	$1.248	$ .922	$ .683	$ .377
Foreman and asst. foreman	.074	.082	.086	.061	.093	.044	.042	.045	.013
Waterboy, teaming and watching	.126	.129	.140	.072	.105	.083	.044	.068	.006
Calkers and laborers	.750	.788	.629	.676	.816	.463	.450	.407	.150
Total labor	$ .950	$ .999	$ .855	$ .809	$1.014	$ .590	$ .536	$ .520	$ .169
Total cost per foot	$7.019	$5.818	$5.007	$2.995	$3.063	$1.838	$1.458	$1.203	$ .546

*On 30-in. mains 24-in valves were set and on 24-in and 30-in. mains 20-in. valves were set.
†Includes paving and other items of like nature.

pipes were laid with the axis of the pipe 5 ft. below the surface. The pipes were usually placed in the trench by a hand operated derrick spanning the trench. In practically all cases the streets were macadamized. Just how many feet of each kind of pipe were laid is not stated; but there were not less than the following amounts:

12-in. pipe	15,500 ft.
16-in. pipe	44,600 ft.
20-in. pipe	21,200 ft.
24-in. pipe	19,600 ft.
30-in. pipe	7,200 ft.
36-in. pipe	36,800 ft.
48-in. pipe	97,900 ft.

The first item in Table III of $30 per ton for pipe was calculated by adding 12% to the actual cost of $26.80 per ton, this 12% being added to cover incidentals. These incidentals are as follows, by percentages:

	Per cent.
Small pipes for blow-offs and connections	1½
Special castings	4½
Valves	5
Miscellaneous materials	1
Total percentages to be added to the cost per short ton of straight pipe	12

The cost of teaming on 21 contracts previous to 1898 was 26 cts. per ton per mile, the average haul being 2.4 miles from the pipe yards; but, in order to be liberal, 30 cts. per ton per mile for a 2½-mile haul is assumed as an average; wages of two-horse team and driver being 45 cts. per hr.

The lead is estimated at 5 cts. per lb., and each joint requires about as many pounds of lead as 2 times the diameter of the pipe in inches, according to Mr. Saville, but other authorities do not agree with him.

The column headed "miscellaneous expenses" is based upon actual experience, and includes cost of tools, insurance of men, lumber, yarn, and incidental expenses. The tools depreciate about 50% on any contract. It was estimated that 4% of the cost of laying the pipe should be added to cover the cost of tools. The cost of accident insurance was 3% of the pay roll. The contractor's bond cost ½% of the bond. Incidental expenses were about 1% of the pay roll. It was estimated that these three items amounted to 3.2% of the cost of laying the pipe. The cost of lumber, yarn, etc., averaged 2.8% of the cost of hauling and laying. Hence, the total cost of "miscellaneous expenses" was 4% + 3.2% + 2.8%, which is 10% of the cost of laying the pipe. The word "laying" is here used to include the cost of hauling the pipe, the cost of lead, the cost of trenching and backfilling, and the cost of placing the pipe in the trench and calking it.

The column headed "labor" includes the cost of trenching in earth (there was very little rock), and the cost of placing the

TABLE III.—COST OF PIPE AND LAYING PER LINEAR FOOT AT BOSTON.

Size of Pipe. Inches.	Weight per length. Pounds.	Weight per linear foot. Tons. (2,000 lbs.)	Cost @ $30.00 per ton.	Teaming, 30c. per ton mile. Haul 2½ miles.	Lead, 5c. per pound.	Miscel-laneous expenses.	Labor.	Total cost.
12*A	810	0.034	$1.02	$0.025	$0.100	$0.065	$0.45	$1.66
*E	1,040	0.043	1.29	0.035	0.100	0.065	0.46	1.95
14 A	1,010	0.042	1.26	0.030	0.120	0.070	0.46	1.94
E	1,310	0.055	1.65	0.040	0.120	0.070	0.47	2.35
16 A	1,215	0.051	1.53	0.040	0.130	0.070	0.50	2.27
E	1,610	0.067	2.01	0.050	0.130	0.070	0.51	2.77
18 A	1,400	0.058	1.74	0.040	0.150	0.080	0.56	2.57
E	1,910	0.080	2.40	0.060	0.150	0.080	0.58	3.27
20 A	1,610	0.067	2.01	0.050	0.180	0.090	0.61	2.94
E	2,260	0.094	2.82	0.070	0.180	0.090	0.64	3.80
24 A	2,050	0.085	2.55	0.060	0.200	0.110	0.70	3.62
E	3,000	0.125	3.75	0.090	0.200	0.110	0.73	4.88
30 A	2,860	0.119	3.27	0.090	0.250	0.130	0.78	4.52
E	4,340	0.181	5.43	0.135	0.250	0.135	0.83	6.78
36 A	3,800	0.158	4.74	0.120	0.300	0.140	0.88	6.18
E	5,900	0.246	7.08	0.185	0.300	0.145	0.93	8.64
42 A	4,920	0.205	6.15	0.155	0.350	0.175	1.02	7.85
E	7,720	0.322	9.66	0.240	0.350	0.180	1.12	11.55
48 A	6,130	0.256	7.68	0.190	0.400	0.240	1.47	9.98
E	9,740	0.407	12.21	0.305	0.400	0.245	0.57	15.73
54 A	7,510	0.312	9.36	0.235	0.450	0.275	1.66	11.98
E	12,400	0.516	15.48	0.390	0.450	0.280	1.76	18.36
60 A	8,900	0.370	11.10	0.275	0.500	0.325	1.96	14.41
E	15,100	0.628	18.84	0.470	0.500	0.330	2.12	23.27

*A is light-weight pipe. E is heavy-weight pipe.

pipe in the trench and calking it. Wages paid for labor were as follows:

Foreman	$100.00 per month
Sub-foreman	3.00 per day
Calkers and yarners...........	2.50 "
Laborers, 1st class............	1.75 "
Laborers, 2d class.............	1.60 "
Double team and driver........	0.45 per hour
Single team and driver........	0.30 "

A considerable amount of extra work was done by force account on 38 miles of the pipe lines, averaging 12 cts. per ft. of line, due to obstructions encountered causing changes of location, etc.

Cost of Laying Main Water Pipe in Boston, Mass., 1878-1907.*— The gradual increasing average labor cost of laying water pipe

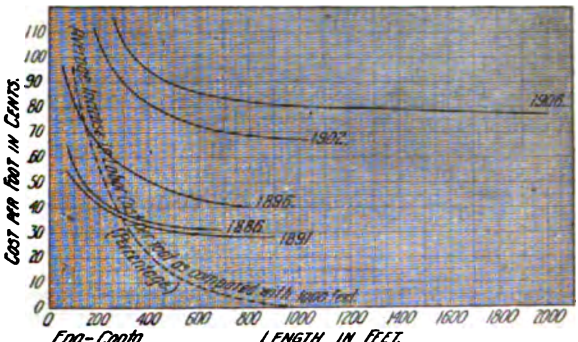


Fig. 4.—Effect of Length of Job on Cost.

in Boston is made the subject of one of the reports prepared by Metcalf & Eddy, consulting civil engineers to the Boston Finance Commission. Nearly all the pipe laid was 8-in. pipe; but some 6-in. and 10-in. pipe is included and a little 12-in. pipe. Since, however, this range in sizes involves substantially no change in trench dimensions the cost per foot should be directly comparable. The average labor costs per lineal foot of laying water pipe, taken from the city engineer's records for the years 1878 to 1907, inclusive, are given in Table IV. These are the figures on which the engineers' computations which follow are based.

It will be seen from the table that, during the period covered, wages advanced, the hours of labor decreased and the labor performed per hour also advanced.

Figure 4 shows the general relation of the cost per foot to the

---

**Engineering-Contracting*, Aug. 18, 1909.

TABLE IV.—LABOR COST PER LINEAR FOOT OF LAYING WATER PIPE IN BOSTON.

Year.	Wages per day.	Number of jobs.	Total length of pipe (feet).	Av. length of job (feet).	Hours per week.	Labor cost per foot in cents. Max.	Min.	Av. actual cost.	Av. cost reduced to uniform basis of $2 per day, 60 hrs. per week.	Av. cost further reduced to uniform av. length of job (500 ft.)
1878........	$1.75	9	4,398	489	60	35.4	17.2	22.3	25.5	25.3
1879........	1.75	4	3,110	778	60	29.5	17.4	22.7	25.9	26.4
1880........	1.75	9	4,258	473	60	74.9	25.0	32.3	36.9	36.6
1881........	1.75	2	557	279	60	33.6	29.4	32.0	36.6	32.7
1882........	1.75	..	.....	...	60	....	....	35.0	40.0	....
1883........	2.00	15	4,787	319	60	49.6	27.4	37.3	37.3	34.0
1884........	2.00	20	8,710	435	60	75.0	22.6	33.1	33.1	32.1
1885........	2.00	14	3,065	219	60	79.1	21.4	38.8	38.8	33.7
1886........	2.00	29	7,056	243	60	141.6	21.0	37.1	37.1	32.5
1887........	2.00	38	13,943	367	60	104.2	21.9	37.2	37.2	34.8
1888........	2.00	38	11,203	295	60	119.7	19.5	38.9	38.9	35.0
1889........	2.00	48	14,215	296	60	105.94	13.63	35.26	35.26	31.8
1890........	2.00	30	6,306	210	60	105.0	15.52	43.05	43.05	37.1
1891........	2.00	74	20,428	276	54	94.83	16.32	36.82	33.1	29.6
1892........	2.00	59	16,527	280	54	242.4	24.0	43.7	39.3	35.0
1893........	2.00	23	7,593	330	54	63.6	20.4	37.2	33.5	30.7
1894........	2.00	45	19,037	423	54	215.3	11.5	41.3	37.2	36.8
1895........	2.00	36	17,353	482	54	88.6	18.8	44.6	40.1	39.8
1896........	2.00	39	13,975	358	54	282.6	16.7	47.3	42.6	39.6
1897........	2.00	21	9,613	458	50	112.5	21.1	51.5	42.9	42.0
1898........	2.00	22	10,628	483	50	95.8	36.4	61.3	51.1	50.6
1899........	2.00	31	11,685	377	50	149.3	32.9	64.1	53.4	50.4
1900........	2.00	19	8,502	447	44	99.6	28.2	63.1	46.3	44.9
1901........	2.00	11	3,478	316	44	130.5	47.2	81.8	60.0	54.6
1902........	2.00	14	8,789	628	44	185.6	60.1	83.4	61.2	65.1
1903........	2.00	9	3,765	418	44	121.6	43.4	80.7	59.2	56.9
1904........	2.00	9	3,704	411	44	93.0	55.6	74.5	54.6	52.5
1905........	2.00	12	5,745	477	44	148.2	51.7	88.5	64.9	64.2
1906........	2.00	22	15,178	690	44	139.1	57.1	83.3	61.1	67.2
1907........	2.00	13	5,979	460	44	130.6	66.8	81.0	59.4	58.2

length of the job for five of the years under consideration, viz.: 1886, 1891, 1896, 1902 and 1906. It will be seen that the form of curve is substantially similar in all cases. From these curves was computed the increase in labor cost per foot for shorter jobs as compared with the cost for 1,000 ft., in percentages, and the results shown by the dotted curve on the same diagram. This curve shows that the increased cost per foot of a piece of work 100 ft. long, over what it would have been if 1,000 ft. long, is 90 per cent. The increased cost for a 200-ft. job is 55 per cent; for 300 ft., 34 per cent; for 400 ft., 21½ per cent; for 500 ft., 13 per cent, and for 600 ft., 8 per cent.

From the same line of reasoning it is readily apparent that in years when the average length of job is high, the corresponding cost per foot should be less than when the average length is low. From their study of the relations of average length to average total cost per foot, partly by mathematical work and partly by the exercise of judgment, the engineers deduced factors by which the costs can be reduced to an average annual length of job of 500 ft.; the labor cost so reduced is given in the last column of the table. In others words, this column is intended to show costs which should be absolutely comparable in all particulars, having been reduced not only to a uniform basis of wages and hours of labor, but also to a uniform basis of average length of job.

The results are indicated somewhat more clearly by Fig. 5, showing by the light line the average labor cost as computed by the city engineer for uniform conditions of wages and hours of labor, and by the heavy line the further reduction for a uniform length of job. This latter line shows, under the assumed basis, the average labor cost of about 33 cts. per foot to and including 1893, and a rapidly increasing cost up to 1906. On this diagram the dotted lines show the effect of omitting the work done by contract in 1904, 1905, 1906 and 1907, which had been included by the city engineer. On this basis it is seen that the cost in 1906 and 1907 was somewhat less than in 1905, although greater than in any preceding year.

Further comment upon these diagrams is perhaps superfluous. Metcalf & Eddy emphasize the statement that the increased labor cost can be charged to nothing but inefficiency of labor.

This inefficiency is due to various causes. The engineers elsewhere reported in some detail showing the effect of age upon efficiency. Other causes which doubtless have greater or less effect are lack of discipline, political appointments, and more or less inefficient organization.

Comparative Cost of Pipe Laying in New England Cities.*—As a part of the report by the special Boston Finance Commission, which recently completed its labors, there has been published a volume of some 1,200 pages comprising solely the reports (nearly 60 in number) of Metcalf & Eddy of Boston, consulting civil engi-

---

**Engineering-Contracting*, July 28, 1909.

In their investigation of the Boston Water Department the engineers made a careful study and analysis of the cost of pipe laying and for the purpose of comparison also investigated the cost of laying pipe by day labor in neighboring cities of Massachusetts. The basis of actual cost differs, in some cases considerably, since the trenches are not of the same dimensions and since wages and

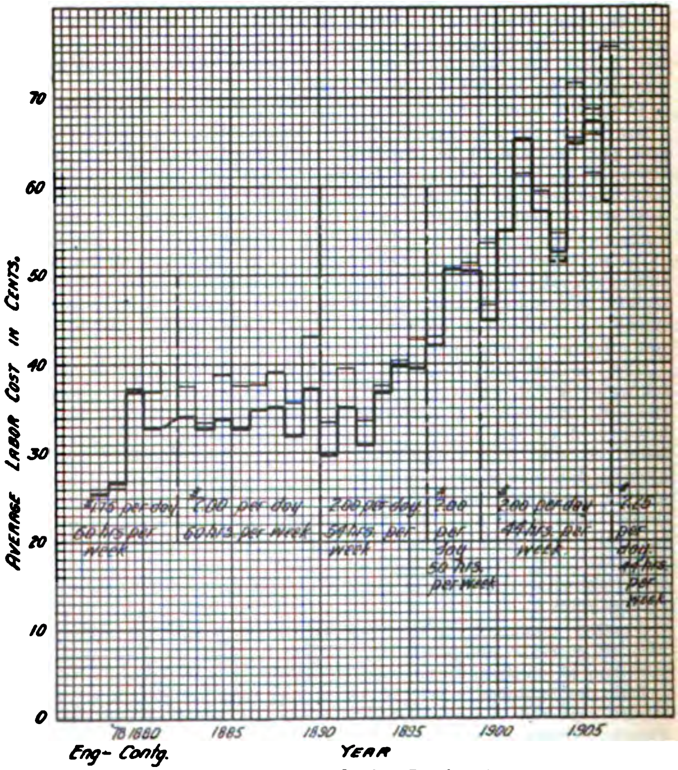


Fig. 5.—Increasing Cost of Pipe Laying in Boston.

hours of labor vary more or less. The engineers attempted, however, to reduce the cost to a uniform basis, so far as possible. Since the data for adjoining cities are based on present costs, or at least costs within a period of a year or two previous to the date of the report, they took the average labor cost of pipe laying in Boston for the 2½ years from 1905 to July 1, 1907, inclusive, for comparison.

In Table V are given, following the name of each city, the wages and hours of common labor during the period under discussion; the length of pipe included in making up the average cost; the years in which this pipe was laid; the actual labor cost per foot; the depth of trench; the corresponding cost per foot for a trench 6 ft. deep, such as is used in the city of Boston; and, finally, the corresponding cost for a 6-ft. trench, if the wages had been uniformly $2 per day and the hours 60 per week.

In making the computations, it was assumed that a trench 6 ft. deep would cost 20 per cent more per foot than one 5 ft. deep. As a matter of fact the actual increase in cost would probably be something less than 20 per cent, since there would be very little if any increased cost of placing the pipe, making joints, etc., and no increase in the cost of teaming. On the other hand, the cost of excavation for the lowest foot might be a little greater than one-fifth of the average cost, but in most cases probably not enough greater to offset the practically unchanged cost of the items mentioned above. The addition of 20 per cent is, therefore, probably more than ample to allow for the increased depth of trench.

In reducing the actual costs to what they would have been had the wages been $2 per day and the hours 60 per week, it has been assumed that the actual efficiency of labor per hour was unaffected by the change in hours and wages.

The figures in the last column of the table should be absolutely comparable. The greater difficulties encountered in Boston on account of many obstructions, etc., do not enter, since all jobs involving such difficulties have been rigidly excluded from the computations and comparisons.

From them it is evident that the pipe laying cost in the city of Boston is 69 per cent greater than that of the average of the other seven cities, and nearly 44 per cent greater than the cost in Worcester, where it is the highest of any of the seven.

In the case of Cambridge, besides data showing the cost in 1905, average labor cost per foot was furnished of laying 4, 6, 8 and 12-in. pipe from 1894 to 1903. The fluctuations in these costs are not remarkable and there was no wide divergence from the average during this period of ten years. After adding 20 per cent to make the figures comparable with those for 6-ft. trench in Boston, the average for the ten years was 40.4 cts. per foot for all sizes, or, separating the figures, 31.4 cts. for 4-in. pipe, 35.1 cts. for 6-in., 43.4 cts. for 8-in. and 51.6 cts. for 12-in. In 1905, however, as already noted, the average cost on the comparative basis was 50.3 cts. per foot, an increase of 49 per cent over the average for the ten years 1894-1903. No data were furnished which explained this sudden increase.

Reducing 40.4 cts. per foot to the $2 per day and 60 hours per week basis, the comparative labor cost of pipe laying in Cambridge prior to 1904 was found to be 31.6 cts. per foot. During this same period, 1894-1903, the labor cost in Boston reduced to the same basis was rapidly increasing and ranged from 37.3 cts. at the be-

TABLE V.—SHOWING COMPARATIVE LABOR COST OF LAYING PIPE IN VARIOUS CITIES.

City	Actual average wages and hours of common labor. Wages.	Actual average wages and hours of common labor. Hours.	Length of pipe included in computing average cost. Feet.	Year.	Actual cost of labor per ft. of pipe. Cents.	Depth of trench. Feet.	Computed cost of labor per ft. of pipe for 6-ft. trench. Cents.	Corresponding cost of labor per ft. of pipe with wages $2 and hours 60 per week —trench 6 ft. deep. Cents.
Boston	$2.00	44	12,151	1905-06-07 (to July 1.)	96.1	6	96.1	70.5
Worcester*	2.00	48	5,551	1907	50.9	5	61.1	48.9
Cambridge	2.00	47	......	1905	50.25	5	60.3	47.3
Lowell	2.00	48	5,915	1907	49.1	5	58.9	47.1
Somerville	2.00	47	2,418	1906	45.2	5	54.2	42.5
Newton	1.75	48	2,238	1906-07	53.0	6	53.0	42.4
New Bedford	2.00	48	15,720	1907	34.7	5	41.6	33.3
Chelsea	2.00	46	2,474	1906	32.7	5	39.3	30.1
Average of all except Boston	2.00	..	.....	....	....	..	....	41.7

*It should be noted that a portion of thework done in Worcester in 1907 showed extremely high costs and the average cost is therefore high. Had the year 1906 been taken the average cost in last column would have been $4.7c.

ginning of the period to 59.3 cts. at the end, or from 18 per cent to 88 per cent more than the cost in Cambridge.

Metcalf & Eddy show that from the foregoing information it can only be concluded that under labor conditions as they exist in other neighboring cities, a fair average labor cost for pipe laying work, reduced to the uniform basis of $2 per day and 60 hours per week, would be about 42 cts. per foot, with 50 cts. as a maximum. Of course individual pieces of work would often exceed the average and others would frequently fall considerably below it. As against these fair costs, this work cost the city of Boston, on the same basis of hours and wages, about 70 cts. per foot for the three years prior to July, 1907, or from 10 to 70 per cent in excess of its reasonable cost.

Reduced to the basis of hours and wages, at the time of the report (i. e., 44 hours per week and $2.25 per day), the fair average labor cost as estimated upon the basis of cost in other cities would be 63.7 cts. per foot, with 76.6 cts. as a reasonable maximum, against which the average cost for the previous 2½ years (on the same basis) was equivalent to $1.081 per foot, an excess of 44.2 cts. per foot, or 69 per cent, over the fair average cost.

It is difficult to estimate the total excess cost resulting from this inefficiency of labor. The lengths of pipe laid from which the average costs were computed—including only those jobs on which there were no special difficulties which might render them not comparable with other jobs, and including no rock excavation—constitute but a small part of the total pipe of these sizes (6 to 12 ins.) actually laid. It is probable that on the jobs involving special difficulties, where the actual labor costs must have been greater, the excess over a reasonable cost was also larger; and on contract jobs, which have usually been done at a less cost than the day labor jobs, the excess over a reasonable cost would be less. The total length of 6-in. to 12-in. pipe laid in the year 1906-7, as stated in the last annual report of the Boston Water Department, was 57,949 ft. If the excess labor cost on all of this may properly be taken as 44.2 cts. per foot on the $2.25 per day basis, equivalent to 39.2 cts. on the $2 per day basis, then the city actually paid $22,000 more than it should have done for labor alone, in laying pipe of 6-in. to 12-in. diameter in 1907.

The total length of main pipes laid in the year 1906-7 was 71,307 ft. Since the inefficiency of labor is not confined to work upon small sizes of pipe, and is experienced in some degree upon the contract work as well as upon that done by day labor, the engineers estimate that this inefficiency resulted in a total excess of cost of pipe laying, for labor alone, amounting to something like $20,000, and possibly much more, for the year ending January 31, 1907.

Cost of Water Pipe Laying and Placing Hydrants at Atlantic City.—Mr. Kenneth Allen gives the following data relative to the laying of pipe at Atlantic City, N. J., in 1905. The work was done by the Water Department. A 4-in. pipe line, 5,000 ft. long,

was laid in a trench 40 ins. deep, in sand requiring no shoring or pumping.

The average force employed was as follows:

	Per 8 hr. Day.
Trenching and back filling:	
10 men at $1.50	$15.00
½ foreman at $2.00	1.00
Total, 292 lin. ft. at 5.5 cts	$16.00
Pipe Laying:	
4 pipe handlers at $1.75	$ 7.00
2 calkers at $2.50	5.00
1 lead man at $2.00	2.00
½ foreman at $2.00	1.00
Total, 292 lin. ft. at 5.1 cts	$15.00

The total cost per lineal foot of 4-in. pipe was:

	Cts. per ft.
19.66 lbs. cast iron pipe at 1.11 cts	21.59
Specials, at 2½ cts. per lb	1.69
Valves and boxes	6.26
0.45 lbs. lead at 4.9 cts. per ton	2.22
0.024 lbs. Jute, 5½ cts. per ton	0.13
0.28 lbs. coke	0.08
Hauling at 75 cts. per ton	0.80
Trenching, as above detailed	5.50
Pipe laying, as above detailed	5.10
Watchman	0.60
Superintendence	1.25
Total	45.22

The average cost of setting 10 hydrants (4 in.) was as follows per hydrant:

Material	$3.26
3 days (24 hrs.) at $1.50	4.50
Total	$7.76

The following was the cost of 4,300 ft. of 8-in. pipe:

	Per. ft.
46.5 lbs. pipe at $22 ton	$0.511
1.04 lbs. lead at 4.9 cts	0.054
Jute at 5½ cts.	0.023
Specials, valves, hauling, etc	0.217
Labor	0.290
Total	$1.095

The following was the cost of 3,200 ft. of 10-in. pipe:

	Per ft.
68.7 lbs. pipe	$0.762
2.04 lbs. lead	0.098
Jute	0.046
Specials, valves, hauling, etc	0.124
Labor	0.560
Total	$1.590

The following was the cost of 3,600 ft. of 12-in. pipe:

	Per ft.
84.3 lbs. pipe	$0.936
2.77 lbs. lead	0.122
Jute	0.042
Specials, valves, hauling, etc.	0.272
Labor	0.790
Total	$2.165

It will be noted that the labor cost for the 8, 10 and 12-in. pipe was abnormally high, said to be due to expensive crossings of other pipe lines and to the presence of adjacent gas pipes, etc., which had to be cared for.

Cost of Laying a 14-in. Pipe Line, Wilkes-Barre, Pa.*—The work consisted of laying 750 ft. of 14 in. bell and spigot pipe at Wilkes-Barre, Pa., in October, 1905. The work was done by company labor and the digging was easy. The pipe was distributed with a truck on a narrow gage track along the trench. The pipes were placed in the trench by a hand-operated derrick spanning the trench. The cost of the pipe line was as follows:

Materials:	Total.	Per ft
62 pieces 14-inch pipe, 77,773 lbs.	$ 937.16	$1.25
6 pieces 14-inch bends, 2,852 lbs.	74.87	10
Freight on pipe and bends	50.39	.067
1,421 lbs. lead at $0.05	72.05	.096
68 lbs. hemp at $0.09	6.12	.008
Total cost of material	$1,140.59	$1.521
Labor:	**Total.**	**Per ft.**
Excavating and distributing pipe, 64 days at $1.74	$ 111.36	$0.148
Laying and calking, 21 3/9 days at $1.74	37.12	.050
Covering over, 12 2/9 days at $1.74	23.01	......
Covering over, 2 days at $1.79	3.58	.035
Superintendence and engineering	12.20	.016
	$ 187.27	$0.249
Total cost of material and labor	$1,327.86	$1.770

For the above information we are indebted to Mr. Douglas Bunting, Chief Engineer, Lehigh & Wilkes-Barre Coal Co.

Cost of Water Pipe Laid at Alliance, O.—Mr. L. L. Tribus gives the following costs of work done in 1894, the material being loam and clay excavated to such a depth that 4 ft. of earth would be left on top of each class of pipe after backfilling:

Size of pipe in ins.	4	6	8	10	12
Wt. of pipe, lbs. per ft.	19	30½	44	62	79
Lbs. special per ft.	0.4	0.76	1.1	1.55	1.9
Lbs. lead per ft.	0.4	0.66	1.0	1.25	1.5
Lbs. yarn per ft.	0.02	0.025	0.05	0.08	0.1
Total length in ft.	2,890	9,760	1,860	3,320	2,930

**Engineering-Contracting,* Nov. 7, 1906.

Cost Per Lin. Foot. Laid.

Size of pipe in ins.	4	6	8	10	12
Pipe	$0.2360	$0.3780	$0.5350	$0.7470	$0.9400
Specials and valves	.0120	.0189	.0268	.0374	.0470
Hauling	.0056	.0078	.0110	.0145	.0190
Lead	.0020	.0330	.0500	.0630	.0750
Yarn	.0014	.0018	.0035	.0056	.0070
Trenching	.1240	.1210	.1287	.1480	.1902
Pipe laying	.0370	.0346	.0313	.0542	.0463
Total	$0.4360	$0.5951	$0.7863	$1.0697	$1.3245

This work was done by laborers and men employed by the water company and does not include cost of superintendence. The 4-ft. cover over the pipe was in some cases exceeded. The digging was comparatively easy with little ground water to bother. Mr. Tribus informs me that the wages paid were: Laborers, $1.25; pipe handlers, $1.50; and calkers, $2.25, per 10-hour day.

Cost of Water Pipe and Service Connections at Porterville, Cal.—Mr. P. E. Harroun gives the following data on laying 4, 6, 8 and 10-in. water pipe and making service connections, at Porterville, Cal., in 1904. The work was done by company labor, and the workmen were very inefficient. All trenches were 1½ ft. wide and 3½ ft. deep in a heavy adobe (clay), except for short stretches in sand as hereafter noted. The streets were not paved, but covered with 4 ins. of hard rolled clay and gravel which required a 4-horse plow to break through. In backfilling, a "go devil" was used to throw the material into the trench wherever practicable, and water from street hydrants was used to consolidate the back fill.

Cost of 4-in. water pipe line (2,846 ft. long, of which 900 ft. were in sand):

	Per ft.
Labor trenching, at 20 cts. per hr.	$0.070
Two horses trenching, at 15 cts. per hr.	0.001
Labor digging bell-holes, at 20 cts. per hr.	0.015
Labor laying pipe, at 20 cts. per hr	0.010
Yarners, at 22½ cts. per hr.	0.005
Labor pouring lead, at 20 cts. per hr.	0.004
Calkers, at 25 cts. per hr.	0.008
Labor backfilling, at 20 cts. per hr.	0.011
Two horses backfilling, at 15 cts. per hr.	0.004
Distribution of materials, at 60 cts. per ton	0.005
Miscellaneous labor	0.004
Foreman, at 40 cts. per hr.	0.017
Timekeeper	0.002
Total cost of laying per ft.	$0.156

The cost of materials for this 4-in. pipe line was as follows:

	Per ft.
Pipe (2,820 ft., 30 short tons), $44.40	$0.461
Specials (4,462 lbs.), at 3¼ cts.	0.051
Valves (9), at $9.40	0.030
Hydrants (5), at $28.60	0.050
Lead (2,010 lbs.), at 5.3 cts	0.038
Yarn (105 lbs.), at 5.4 cts	0.002
Tools	0.015
Miscellaneous	0.006
Total materials per ft.	$0.653

Cost of 6-in. water pipe line (838 ft. long, of which 300 ft. were in sand):

	Per ft.
Labor trenching, at 20 cts. per hr	$0.075
Two horses trenching, at 15 cts. per hr	0.001
Labor digging bell-holes, at 20 cts. per hr	0.017
Labor laying pipe, at 20 cts. per hr	0.013
Yarners, at 22½ cts. per hr	0.005
Labor pouring, at 20 cts. per hr	0.007
Calkers, at 25 cts. per hr	0.010
Labor backfilling, at 20 cts. per hr	0.012
Two horses backfilling, at 15 cts. per hr	0.004
Miscellaneous	0.005
Distribution of materials, at 60 cts. ton	0.012
Foreman, at 40 cts. per hr	0.018
Timekeeper	0.002
Total cost of laying per ft	$0.181

The cost of materials for this 6-in. pipe line was as follows:

	Per ft.
Pipe (816 ft., 13.12 tons), at $43.40 per ton	$0.679
Specials (1,420 lbs.), at 3¼ cts	0.055
Valves (10), at $15.65	0.187
Hydrants (9), at $29.85	0.320
Lead (804 lbs.), at 5.3 cts	0.052
Yarn (42 lbs.), at 5.4 cts	0.003
Tools	0.016
General	0.010
Total materials per ft.	$1.322

Cost of 8-in. water pipe line (2,558 ft. long, of which 800 ft. were in sand):

	Per ft.
Labor trenching, at 20 cts. per hr	$0.071
Labor digging bell-holes, at 20 cts. per hr	0.016
Labor laying pipe, at 20 cts. per hr	0.016
Yarners, at 22½ cts. per hr	0.006
Labor pouring, at 20 cts. per hr	0.006
Calkers, at 25 cts. per hr	0.013
Labor backfilling, at 20 cts. per hr	0.012
Two horses backfilling, at 15 cts. per hr	0.004
Miscellaneous	0.004
Distributing materials, at 60 cts. per hr	0.016
Foreman, at 40 cts. per hr	0.017
Timekeeper	0.002
Total cost of laying per ft	$0.183

The cost of materials for this 8-in. pipe line was as follows:

	Per ft.
Pipe (2,512 ft., 57.61 tons), at $43.40	$0.978
Specials (4,056 lbs.), at 3¼ cts	0.052
Valves (5), at $24	0.047
Lead (3,618 lbs.), at 5.3 cts	0.076
Yarn (189 lbs.), at 5.4 cts	0.004
Tools	0.015
Miscellaneous	0.009
Total materials per ft.	$1.181

Cost of 10-in. water pipe line (124 ft. of pipe, 14 ft. of specials; total, 138 ft.):

	Per ft.
Labor trenching, at 20 cts. per hr	$0.174
Labor digging bell-holes, at 20 cts. per hr	0.015
Labor laying pipe, at 20 cts. per hr	0.022
Labor yarning, at 20 cts. per hr	0.002
Labor pouring, at 20 cts. per hr	0.002
Labor calking, at 20 cts. per hr	0.015
Labor backfilling, at 20 cts. per hr	0.060
Labor miscellaneous, at 20 cts. per hr	0.015
Distribution of materials, at 60 cts. ton	0.020
Foreman, at 40 cts. per hr	0.016
Timekeeper	0.002
Total labor per ft	$0.343

The cost of materials for this 10-in. pipe line was as follows:

	Per ft.
Pipe (124 ft., 3.74 tons), at $43.40	$1.179
Specials (603 lbs.), at 3¾ cts	0.178
Valves (1), at $34.60	0.251
Lead (268 lbs.), at 5.3 cts	0.105
Yarn (14 lbs.), at 5.4 cts	0.005
Tools	0.015
Miscellaneous	0.009
Total materials per ft	$1.742

Cost of service connections (¾-in. screw pipe):

	Each.
Labor trenching, at 20 cts. per hr	$0.613
Tapping and making, at 40 cts. per hr	1.003
Tapping and helper, at 20 cts. per hr	0.289
Backfilling, at 20 cts. per hr	0.206
Total labor per connection	$2.111

The cost of materials for each service connection was as follows:

	Each.
Goosenecks and cocks	$2.48
Fittings	0.40
Tools ($68)	0.88
Tapping machine ($81)	1.03
Total materials and tools per connection	$4.79

It will be noted that the full cost of the tools and tapping machine is charged to these 78 connections, making the cost of each unusually high.

Assuming, as above stated, that the trenches averaged 1½ ft. wide and 3½ ft. deep, the cost per cubic yard of trench work was as follows:

	Cents.
Digging trench	38
Digging bell-holes	8½
Backfilling	8½
Total per cu. yd.	55

An Unusually Expensive Piece of Work.—"G. S. W. '88" in The Technic of 1896, gives the following, the material in all cases being clay: Wages of laborers 15 cts., pipe handlers 16 to 17½ cts., foreman 20 cts. per hour; depth of trench, 4 to 5½ ft.:

Example	A	B	C	D
Size of pipe, ins.	24	24	12-16	10
Length of pipe, ft.	2,550	2,200§	6,241	8,969
Excavation, cu. yds.	2,710	1,963	3,441	4,508
Surplus earth,* cu. yds.	1,300	862	1,033	....
Cost of excavation per ft.	$0.2725	$0.333	$0.2061	$0.2416
Cost of pipe laying, per ft	.2480	.182	.2089	.0939
Cost of bell holes, per ft.	.1500	.128	.0954	.0098
Cost of backfilling, per ft	.1790	.191	.1228	.1360
Cost of ramming, per ft.	.7927†	.107‡	.2896†	.1322†
Cost of tile, hose work, per ft.	.....	.074	.....	.0200
Cost of loading excess earth, ft.	.0895	.046	.0358	.0025
Cost of carting excess earth, ft.	.0636	.055	.0635	.0046
Total labor cost per ft.	$1.7953	$1.116‡	$1.0318||	$0.6433
Cost of excavation, cu. yd.	0.2562	0.373	.3736	.4807
Cost of backfilling, cu. yd.	0.1684	0.216	.2226	.2706
Cost of ramming cu. yd.	0.7461†	0.121||	.5434†	.8618†
Cost of tile, hose work, cu. yd.	.....	0.084	.....	.....
Swelling of material on loosening	44%	30. to 44½%*	20%	.....

*This surplus earth was hauled away in wagons, after filling the trenches and leaving a 4-in. crown to provide for settlement.

§1,400 feet of this trench was backfilled without ramming, using water instead; ramming, however, was much more effective in compacting the clay.

†Rammed dry in 4-in. layers.

‡Rammed wet; the portion that was rammed dry cost $1.40 per ft. total.

||This total does not check with the items, so there must be an error somewhere.

With labor at $1.25 for 8 hours and material clay as before, streets paved with wood. "G. S. W." also gives the following:

Example	E.	F.	G.	H.
Size of pipe in ins.	12	12	10	8
Depth of trench, ft.	5	5	5	5
Length of trench, ft.	1,048	2,475	2,592	2,049
Cost of excavation, per ft.	$0.186	$0.134	$0.1920	$0.1442
" pipe laying, per ft.	.257	.162	.1218	.0678
" backfilling, per ft.	.450	.390	.3949	.3632
" hauling surplus, per ft.	.014	.011	.0101	.0194
Total labor cost per ft.	$0.907	$0.697	$0.7188	$0.5746

The two most striking features in the foregoing data are (1) the enormous swelling of the clay upon loosening and casting it out of the trenches, and (2) the extraordinary high cost of ramming the clay in backfilling. It is difficult to explain either of these items except upon the assumption that the loosened clay dried out when exposed to the sun and air, forming hard rock-like clods which no amount of ramming seems to have consolidated effectually. Adding water as in Example B seems to have had no very good effect in consolidating the backfill, although it was less expensive than ramming. But it is a well-known fact that water makes dry clay swell, and it does not cause layers of hard lumpy clay to

settle in a trench except as a result of weeks of slow seepage of rains.

It will be noted that all this work was extraordinarily expensive. Even the pipe laying cost double the usual amount. We may infer that this work was not done by contract but by day labor for a municipality or a company, and that the foreman did not secure "a day's work" from the men—which is so often the case in municipal day-labor work.

Cost of a 6-in. Pipe Line in Ohio.—Mr. E. H. Cowan has given me the following data: A 6-in. pipe line, 1½ miles long, was laid in an Ohio city by contract, the cost per foot of pipe line to the contractor being as follows:

	Per ft.
33.74 lbs. of 6-in. pipe, at $24 per short ton	$0.405
0.67 lb. of specials, at 2¾ cts. per lb.	0.018
Hydrant connections, 4-in.	0.008
Hydrants, $26 each	0.066
Gates ($12.60 each) and gate boxes ($3.09 each)	0.054
0.74 lb. lead, 4½ cts. per lb.	0.033
0.07 lb. jute packing, 3¾ cts. per lb.	0.003
Labor, 18½ to 26 cts. per ft. averaging	0.211
Teaming, 49½ cts. per short ton	0.009
Miscellaneous items	0.008
Total	$0.815

The working force was as follows:

1 foreman, at $2.50 per 10-hr. day	$ 2.50
2 sub-foremen, at $2.00	4.00
9 men in pipe gang (including 2 calkers), at $1.75	15.75
32 laborers digging trench, at $1.50	48.00
12 laborers backfilling, at $1.50	18.00
1 waterboy, at $1.00	1.00
Total, 423 lin. ft., at $0.211	$89.25

At times the back filling gang was engaged in trench digging. Trenches were 5 ft. 2 ins. deep. The digging ranged from the easiest spading to the hardest picking, the average being "average earth." Could the contractor have been present all the time, the cost might have been less. The backfilling was done by hand, and it was not rammed, but the trench was flushed with water. No material was hauled away. The work was done in August and September, 1903, and there was very little rain. It was not necessary to brace the trench except at a few spots.

Cost of Water Main and Service Pipe Laid in a Southern City.—Mr. C. D. Barstow gives cost of shallow trenching and pipe laying in a southern city, where negro laborers were used. From the data given by him I have compiled the following tables of cost:

For the most part the trenches were 15 ins. wide at bottom and 20 ins. at top, and 3 ft. deep. Some trenching was done using a team on a drag scraper, 20 ins. wide; then the trench was made 3 ft. wide at top. Using teams was more economical, as may be seen by comparing C with D in the foregoing table. After a rain, however, the scrapers could not be used to advantage. In using a plow for loosening the earth, several feet of chain are fastened to the end of the plow beam, and one or more men ride the beam: in

this way plowing may be done in a trench 4 ft. deep, one horse walking on one side and one on the other side of the trench. A blacksmith was kept busy sharpening about 60 picks a day. There was a night watchman. The pipe was distributed by contract at 34 cts. per ton.

TABLE OF COST OF TRENCHING AND PIPELAYING IN THE SOUTH.

Wages per 10-hr. day for negro laborers, $1.25; for calkers, $1.75; for white foremen, $3.00; for teams, $3.25; for horse ridden by boy, $1.50.

Job	A.	B.	C.	D.	E.	F.
Pipe, ins.	10[1]	....	6	8	10	8[8]
Length, ft.	11,000	6,000	6,215	11,352	2,636	21,856
Width trench, ft.	2	....	....	....	....	....
Depth trench, ft.	3.5	3	3	3	3	3
Material	....[2]	....[4]	....	....	....	....[9]
No. laborers digging	33	30	40	31	45	46
No. teams plowing	....	....	....	3½	5	2½
Team time, cts. per ft.	....	....	....	0.80	0.62	0.60
Labor, digging, cts. ft.	6.66	2.74	5.19	2.68	2.12	4.00
Foreman, digging, cts. ft.	0.50	0.23	0.31	0.21	0.12	0.20
Labor, pipelaying, cts. ft.	2.04	....	0.63	0.77	0.94	1.12
Foreman, pipelaying, cts. ft.	0.39	....	0.17	0.21	0.18	0.24
Bell hole digging, cts. ft.	2.70	....	0.77	0.98	0.93	1.16
Bell hole digging, foreman, cts. per ft.	0.27	....	0.16	0.21	0.18	0.18
Calking, cts. per ft.	1.30	....	0.52	0.64	0.63	0.75
Backfill and tamp:						
Labor, cts., per ft.	4.32[3]	1.00[5]	1.01[6]	2.09	1.42[7]	0.95[9]
Foreman, cts. per ft.	0.36	0.22	0.22	0.32	0.18	0.18
Team,* cts. per ft.	....	....	0.36	....	....	0.41
Horse ridden by boy, cts. ft.	....	....	0.07	....	0.09	....
Total cost, cts. per ft.	18.54	4.19	9.46	8.91	7.41	9.79

*Backfill with drag scraper.

[1]Trenching in an old street, 1,200 ft. in very muddy ground. Two rainy spells in 18 days of work. Then 10-in. pipe was laid for 3,440 ft.; then 4,038 ft. of 12-in. pipe were laid for 1¼ cts. per ft. less than it cost for the 10-in. pipe; then 3,270 ft. of 8-in. pipe were laid for 2¼ cts. per ft. less than it cost for the 10-in.

[2]Cemented clay and gravel requiring hard picking. Frequent rains.

[3]The backfilling and tamping were done most thoroughly, a stretch of 2,550 ft. requiring 3 days for 30 men.

[4]Sand and loam, bottom land, very easy digging.

[5]Very easy shoveling and no tamping; 11 men 7 days backfilled 9,620 ft. of trench.

[6]Dragscrapers used to backfill; boy riding horses to tamp, gang 22 men, 3 teams, 1 boy and horse, 2 days on 5,447 ft.

[7]Backfilled 1,670 ft. in one day by 19 men, using 1 boy and horse on tamping.

[8]Half the pipe was 3-in. at cost here given, half was 6-in. costing ½-ct. less per ft. for laying.

[9]Ground wet and often muddy. Backfilling 11,433 ft. done by 12 men and 2 teams on scrapers in 7 days; no tamping.

The lead and yarn consumed per foot of pipe (pipe in lengths of 12 ft.) was:

1.3 lbs. of lead and .04 lb. of hemp for 12-in. pipe.
.96 lb. of lead and .04 lb. of hemp for 10-in. pipe.
.95 lb. of lead and .03 lb. of hemp for 8-in. pipe.
.66 lb. of lead and .02 lb. of hemp for 6-in. pipe.

Some 6,000 ft. of 2-in. wrought-iron service pipe was laid in

trenches 2 ft. deep, at a cost of 1.9 cts. for trenching, 0.24 ct. for laying pipe, and 0.71 ct. for backfilling—there was no tamping done.

For a distance of 373 ft. a trench 2 ft. wide and 3 ft. deep passed through a street paved with brick laid on 7½ ins. of concrete. The brick was removed for a width of 3 ft. and the cost was as follows:

	Men, days.	Cts. per lin. ft.
Removing brick and concrete—Foreman	0.5	
Laborers	7.0	2.61
Excavating trench—Foreman	0.5	
Laborers	18.0	6.30
Backfilling and tamping well—Foreman	1.0	
Laborers	10.6	4.09
Labor relaying concrete	7.8	2.61
Labor relaying bricks	4.5	
Professional brick pavers	4.0	4.59
Professional brick helpers	2.0	
Hauling away 23 loads surplus earth		1.23
15 cu. yds. sand cushion		4.02
1,700 new bricks		6.92
18½ bbls. cement to relay concrete		6.20
Total		38.58

Cost of Hauling, Distributing and Joining Wrought Iron Pipe in Maryland.*—Mr. L. B. Abbott, Chief Engineer The Consolidated Coal Co., Frostburg, Md., gives the following cost for hauling, distributing and joining pipe, in the construction of an 8,000-ft. long pipe line. The work was done in connection with the installation of a water supply for one of the mines of the above-mentioned company.

The pipe, consisting of 4,000 ft. of 6-in. and 4,000 ft. of 8-in. double-strength, wrought-iron pipe, was hauled a distance of eight miles over roads that had to be practically rebuilt in many places. From the main road to the pumping station, a distance of ¾ mile, a new road had to be cut and graded for the heavy loads to be hauled over it. It took five days to haul the pipe to the two distributing points, from 12 to 15 teams being used, each team making one trip a day. Teams were paid for at the rate of $4.50 per day for a 2-horse team. The 4-horse teams, of which there were but two or three used per day, were furnished by the company, and charged at the rate of $8 per team. The teams started to load at 7 o'clock, and by time the 12 or 15 teams were loaded it was generally 10 o'clock. It took from four to five hours to go to the distributing points. It was found that a 2-horse team hauled five lengths of pipe, or about 96 ft. per load, while a 4-horse team hauled nine lengths, or about 170 ft., nine lengths being all that could be loaded into the wagon. The cost of hauling the pipe a distance of eight miles was 4.7 cts. per lineal foot.

From the distributing points a team dragged each length of pipe to its place in the line, the average cost of distributing being nearly 1 ct. per foot.

*_Engineering-Contracting_, Oct. 17, 1906.

While the pipe was being distributed a force of 12 men started to join it up. The men joining and distributing pipe worked about eight hours per day. The greater part of the time they drove to their work. The joining gang was paid as follows: One man at $2.25; three men at $2.20, and eight men at $1.75 per day. The pipe was not buried, but was blocked up about a foot from the ground. The entire 8,000 ft. was laid in ten days. In many places the ground was very rough, and cribs 6 and 7 ft. high had to be built to hold the pipe. The average cost to lay and block up the pipe was 2.9 cts. per foot. This included putting in stay rods every 300 or 400 ft., to keep the pipe from jumping when the pump was running, and the placing of drain cocks in all low places.

Cost of Taking Up an Old Pipe Line.—Mr. E. E. Fitzpatrick furnishes the following data relative to taking up more than 3 miles of pipe line at Greenburg, Kansas. There were 10,200 ft. of 4-in. pipe; 4,310 ft. of 6-in.; 2,050 ft. of 8-in., and 890 ft. of 10-in. After digging the trenches, the 8-in. and 10-in. pipes were raised a little, and fires built under the joints until the pipe expanded; then the pipes were unjointed by working them up and down with a three-leg derrick. The 4-in. and 6-in. pipes were raised bodily in long sections onto the bank, heated a little, and unjointed by means of jack-screws and clamps. The time required to do all the trenching, backfilling and unjointing, was equivalent to the work of 1 man for 425 days; and, assuming wages at $1.50 a day, the cost was only 3¾ cts. per foot of pipe.

Cost of Constructing and Laying Cement Lined Water Pipe, Plymouth, Mass., and Portland, Me.*—Two general methods of building wrought-iron, cement-lined pipe have been used in this country; the first, known as the Goodhue & Birnie pipe, the second, known as the Phipps patent.

The Goodhue & Birnie pipe was generally made by riveting up sheets of wrought iron, single riveted with cold rivets, without any attempt to make the joints water-tight, and lining this wrought-iron shell with from ¾ to 1 in. of neat Rosendale cement, or cement mortar mixed 1 part of cement to 1 part of sand. This work was generally done in a central plant, or at different points along the pipe line, from which the pipe was carried to the trench, there imbedded in Rosendale cement mortar laid along the bottom of the trench, and then covered over the sides and top with a ¾ to 1-in. layer or casing of Rosendale cement mortar plastered on with rubber gloves or trowel in the hands of the pipe maker. The trench was generally backfilled immediately or shortly after laying the pipe.

The pipes were made in lengths of 9 ft., and the joints between the pipes were made by means of a sleeve of wrought iron with inner and outer casing of cement, or by making the pipe tapering so that the end of one pipe was fitted into the end of the next. In the

*Extract from a paper by Leonard Metcalf, M. Am. Soc. C. E., presented to the New England Water Works Association, Dec. 9, 1908, and reprinted in *Engineering-Contracting*, Apr. 7, 1909.

larger mains the joints were often plastered on the inside after laying; in the smaller ones, this was, of course, not attempted.

The Phipps patent pipe was generally made and coated without as well as within with a ¾ to 1-in. layer of cement or cement mortar, the outer coating being held in place by a thin sheet of wrought iron which subsequently rusted out in the trench. This outer sheet was of distinct advantage, however, as a protection to the outer cement coating in the handling and laying of the pipe.

In a few cases cast-iron bells and spigots have been riveted to the wrought-iron sheets before making the pipe, and the joints have then been made in the ordinary manner with lead tightly calked in place or by the use of cement mortar.

More recently under the Phipps patent, a type of cast-iron ring has been developed which is driven home in each end of the pipe,—one of the rings being a female ring, the other a male ring—thus more rigidly holding the end of the pipe and preventing injury to it in transportation and laying, and incidentally making more convenient the placing of the outer cement coating of the pipe, which is made of grout poured into the mold between the inner and outer sheets, with the pipe standing on end. The joint between pipes is made finally by the use of a sleeve as heretofore.

So far as the writer is aware no cast-iron has thus far been developed which has proven thoroughly satisfactory and advantageous from the standpoint of economy.

It is perhaps worthy of note that while blue enameled *wrought-iron* sheets imported from England were used in many of the early installations, in making the later ones steel has been substituted at some saving in cost, though not in durability.

Plymouth, Mass.—Plymouth is a town of about 11,000 inhabitants and has had a water supply since 1776. Until 1855 the water was supplied to the town by a private company and the pipes used were wooden logs with holes bored in them. In 1855 the town purchased the plant from the company, and the use of cement-lined pipe dates from that period.

At that time about 16,000 ft. of 10-in. pipe was laid and several thousand feet of 8-in., 6-in. and 4-in. pipe were laid for the distribution system. Practically all of the pipe laid at that time is still in use.

The pipe as then manufactured consisted of a sheet-iron shell about 9 ft. in length, lined on the inside with about ½ in. of cement mortar, composed of cement and sand in proportions of 1 to 1. The pipe was then laid in a bed of cement mortar in the trench, ends butted together, with a steel sleeve or collar at each joint. The top and sides of the pipe were then covered with two or more inches of cement mortar, all of the same proportions as used for the lining, and a cement-mortar joint was made at each joint of the pipe.

This pipe is still in use and withstands a varying pressure in different sections, from a few pounds to about 50 lbs.

In 1900, somewhat over 40 miles of pipe from 4 to 20 ins. in

diameter was in use. At this time a change in the method of making the pipe was introduced, and for the past seven years all extensions have been made with a pipe manufactured in the local water-works shop, which is furnished with mechanical devices and power machinery necessary for economical manufacture.

The following description will make the present method of construction clear. The pipe consists of a shell, a jacket, male and female rings, and sleeves. The shells and jackets are of soft steel and are received at the shop in flat rectangular sheets of proper size and gage. For the shells of 18-in. pipe about 30 tons of steel sheets of No. 13 gage were used, at a cost of about $50 per ton for the sheets.

The gage of the sheets used for the shells of pipes of different sizes is as follows:

24-in.	12 gage	10-in.	17 gage
18-in.	13 gage	8-in.	18 gage
16-in.	13 gage	6-in.	19 gage
12-in.	15 gage	4-in.	20 gage

The jackets are all No. 26 gage iron. The operation of making the pipe is as follows:

The shells are punched in a punching machine. The spacing of the rivet holes is ¾-in. c. to c., the edge of the rivet hole being ⅝-in. from the edge of the sheet. The sheets are then put into the rolls and given a semi-circular form, as two sheets are used for the manufacture of one shell for the 18-in. pipe. After being rolled, the shells are riveted by hand, using 816 rivets with a 3½-lb. hammer, on a stake, so-called, which is simply a bar of iron about 10 ft. long, the upper surface of which is curved to approximately the same radius as the shell of the pipe which is to be riveted. The jackets are punched, rolled and riveted in precisely the same manner as the shells and are 1½ ins. larger in diameter.

The rings are of cast-iron, a male ring for one end of the shell and a female ring for the other, the female ring being concave and the male ring convex, thus enabling a very tight joint to be made when the pipes are fitted together in the trench. About thirty tons of these rings were used in the manufacture of 16 and 18-in. pipe during the past year and the cost of the rings was 4 cts. per lb.

The next operation, after the shells are riveted, is the fitting in of the rings, and as they are made just for a driving fit into the shell they are driven in by use of the maul. After the rings are in place the shells for the 18-in., 16-in. and 14-in. pipes are lined by hand, and the smaller sizes of shell from 12-in. to 4-in. are lined by means of a revolving cone. Neat Rosendale cement is used in lining. About 3,000 bbls. of cement have been used during the past year in the manufacture of pipe, and the cost was $1.20 per bbl., delivered at our shop.

When the shells are ready to be lined by hand they are placed horizontally on two horses. A man stands at each end of the pipe with a long-handled pallet knife, so-called, to spread the cement smoothly in the pipe. This knife is simply a flat blade about 1½ ins. wide and 4 ins. in length, with a handle about 4 ft. long. The

TABLE VI.—COST OF MAKING CEMENT-LINED PIPE AT PLYMOUTH, MASS.

Date.	Size, ins.	Length, ft.	Shell.	Jacket.	Sleeve.	Rings.	Rivets.	Cement.	Paint.	Labor.	Total.	Cost per ft.
1901.......	6	5,282	$650.94	$326.90	$42.25	$154.17	$25.98	$356.30	$7.14	$513.30	$2,076.98	$0.393
1901.......	4	2,461	186.20	104.74	12.37	43.89	12.29	162.15	1.50	281.25	804.39	0.326
1901.......	10	5,097	146.08	407.43	88.42	255.17	36.42	551.55	10.67	885.45	3,381.29	0.663
1901.......	6	2,007	221.34	100.71	14.02	58.18	10.03	135.41	2.66	177.09	719.44	0.358
1901.......	12	981	305.28	182.40	25.07	55.12	7.00	121.26	2.67	177.08	875.88	0.893
1907.......	16	8,109	3,722.80	852.72	337.50	1,363.35	61.90	1,728.00	15.00	1,954.42	10,035.69	1.240
1907.......	14	2,183	953.44	199.40	59.00	318.60	23.60	384.68	5.00	535.72	2,479.40	1.130
1907.......	18	7,680	3,751.60	836.40	298.80	1,460.80	119.00	1,826.00	18.00	2,457.60	10,828.20	1.410

TABLE VII.—COST OF LAYING CEMENT-LINED PIPE AT PLYMOUTH, MASS.

Date.	Size, ins.	Length, ft.	Labor.	Branches, gate and hydrant.	Pipe.	Cement.	Miscellaneous.	Total.	Cost per ft.	Remarks.
1901.......	12	1,292	$861.90	$418.81	$1,128,62	$70.20	$55.00	$2,534.53	$1.96	Also 47 ft. 6-in. pipe. 105 ft. 6-in., 77 ft. 12-in., 40 ft. 8-in.
1901.......	10	5,430	2,478.28	1,292.21	3,583.47	205.40	173.48	7,732.84	1.43	
1901.......	12	1,292	458.40	108.72	1,153.76	52.00	54.22	1,827.10	1.41	
1904.......	8	3,007	1,035.66	275.67	1,503.50	91.20	72.99	2,979.02	0.99	Includes 4 hydrants and changing 25 services.
1904.......	6	2,543	1,134.97	412.33	933.28	61.88	37.55	2,584.01	1.02	
1905.......	6	4,550	1,854.23	491.38	1,966.16	96.00	385.82	4,793.59	1.05	
1907.......	18	6,545	4,248.80	232.00	9,228.45	440.60	523.60	14,673.45	2.24	
1907.......	14	2,031	552.52	141.00	2,295.03	124.20	86.00	3,201.27	1.56	
1907.......	16	8,891	4,820.00	1,411.12	11,024.84	420.00	1,179.39	18,855.35	2.12	

cement for lining is mixed by hand in mixing boxes, and there are two men to mix for the two men who line. As the pipe lies on the horses it is lined for its whole length and half way up each side. Then the cement is allowed to set, after which the pipe is rolled over and the remaining half lined. After the cement has been smoothly spread about ½-in. thick, on the inside of the pipe, and irregularities which appear are corrected by the use of the "nigger-head," which is a stiff brush on the end of a long handle. This brush in the hands of a skillful workman can bring the interior of the cement pipes to a very smooth surface.

At this point it may be well to describe the operation of lining the smaller sizes of pipe. The shells having been punched, rolled and riveted, and rings put in in precisely the same manner as previously described, are stood upright on an elevator which descends into a pit. In this pit is the cone, so-called, which has an external diameter equal to the internal diameter of the shell when lined—in other words, about an inch smaller in diameter than the shell—placed and held directly over it on the elevator. The cone revolves on a vertical axis and cement mixed by machinery is put in at the top of the shell as it stands on the elevator over the cone. The top of the cone, extending for a few inches into the bottom of the shell, holds the cement from falling through into the pit. The elevator holding the shell is then lowered and the cone revolving at the same time spreads the cement smoothly and uniformly on the inside of the shell.

The next operation is filling and grouting the pipe. The shells are stood on end around the edge of a platform which is about 6 ft. above the floor. A clamp is placed around the bottom of the shell about 8 ins. from the lower end, and the jacket lowered from above fits into the clamp at the bottom. The jacket is kept symmetrical with the shell at the bottom by means of this clamp, and at the top by means of four wedges. The grout is merely a mixture of neat cement and water, mixed to such a consistency that it will pour readily, and is mixed by machinery in a cylindrical mixer which has four paddles. After being thoroughly mixed, the grout is poured into a metal bucket which is suspended by a chain with a wheel and is carried on a track around the platform. The grout is poured from the bucket between the shell and jacket of the pipe that has been stood around the edge of the platform. After the grout has been poured, the pipes are allowed to set twelve hours, when the cement is usually hard enough to permit of handling them. The pipes are then loaded upon a truck, taken to the yard, cleaned, and painted with a coal-tar paint. After staying in the yard about two weeks they are sufficiently hard to permit of being loaded upon a wagon and carted to the trench.

Tables VI and VII show respectively the cost of making and laying the largest cement-lined pipes which have been ma at Plymouth. Town labor, only, is used, and $2 is the wage pa. or a working day of eight hours, for each laborer. The foreman receives $3.

The pipe-making gang numbers about 16 men, but only 4 are

TABLE VIII.—COST OF BUILDING 60,221 FT. 24-IN. WROUGHT IRON CEMENT-LINED SUPPLY PIPE IN 1878-9.

Rights of way, land damages, etc.		$ 1,579.14
Cast-iron pipe, special, castings, valves, etc.		5,024.08
Wrought-iron sheets for pipe:		
441,502 lbs. at 2.43 cts.	$10,728.50	
1,449,562 lbs. at 2.30 cts.	33,339.92	
		44,068.42
Making pipes 9 ft. long: 1,593 pieces at $2.15 and 5,073 pieces at $2.00		13,570.95
Making joint rings, inside rings and special rings: 7,061 rings, weighing 646,310 lbs., at 1.95 cts., approximately, per lb.		12,615.14
Total labor, 24,775 days, at $1.28, approximate average; day labor being paid from $1 to $1.25; foremen, $3.50		31,807.11
Cement, 20,621 bbls. Rosendale		20,180.50
Freight, cartage, etc.		4,148.91
Engineering, incidentals and miscellaneous expenses, amounting to 8.32 per cent, approximately		10,919.67
		$143,913.92
Deduct land damages		1,579.14
Net amount		$142,334.78
Cost per foot		$2.36
Equivalent cost per foot for year 1908 (estimated)		$3.02

TABLE IX.—COST OF BUILDING 18,450 FT. 26-IN. WROUGHT-IRON CEMENT-LINED PIPE.

	Per lb., cts.	Actual cost in 1875-6.	Equivalent prices as of 1908.
Wrought-iron sheets, No. 12, Birmingham gage, 635,679 lbs., at	3.32	$21,230	$18,670
Trimming, rolling, riveting and finishing 2,066 pipe 9 ft. long, at $2.50, equivalent to	0.78	5,020	4,430
Rings	0.90	5,590	4,920
Total, 1875-6	5.0		
Total, 1908	4.4		
Cement (Rosendale), 74,071 bbls., at $1.36 and $1.53½ per bbl.		10,170	7,500
Contract for laying		28,310	42,465
Valves		237	237
Specials		85	85
Lumber		608	1,074
Contract work		141	150
Total		$71,391	$79,531
Cost per foot (including 11.4 per cent for engineering and contingencies)		$3.87	$4.31

kept on the regular gang and the others are hired as they are needed.

Portland, Me.—In the years 1868-9 the Portland Water Co. laid a 20-in. wrought-iron cement-lined supply main, about 15.2 miles long, from Sebago Lake to the city of Portland. Data as to the cost of this main are unfortunately lacking.

In the years 1875-9, however, a second wrought-iron cement-

TABLE X.—ESTIMATE OF COST OF REPRODUCING CEMENT-LINED PIPE IN PORTLAND.

	26-in. Actual price and quantity.	26-in. Estimates for present conditions.	24-in. Actual price and quantity.	24-in. Estimates for present conditions.	20.-in. Estimates for present conditions.
Cost of sheets, per lb.	$0.0342	$0.0275	$0.0233	$0.0275	$0.0275
Cost of cement, per bbl	1.40	1.00	0.98	1.00	1.00
Cost of joint castings per lb.	0.0280	0.0275	0.0195	0.0275	0.0275
Cost of making pipe, per lb.	0.00756	0.0125	0.00718	0.0125	0.0125
Weight per ft., lbs.	37.0	......	31.4	......	21.0
Bbls. cement per foot	0.405	......	0.342	......	0.310
Weight joint rings, lb.	71.0	......	91.0	......	70.0
Weight joint rings, per ft.	8.3	......	10.7	......	8.2
Cost per linear foot of:					
Sheets	$1.26	$1.02	$0.73	$0.86	$0.58
Making pipe	0.28	0.46	0.28	0.39	0.26
Joint castings	0.23	0.23	0.21	0.29	0.23
Cement	0.57	0.40	0.33	0.34	0.31
Gates, valves, etc.	0.05	0.04	0.08	0.07	0.06
Labor and laying	1.48*	2.22	0.53	0.80	1.25
Sum	$3.87	$4.87	$2.11	$2.75	$2.69
Total actual cost, including all special obstacles, engineering and contingencies	$3.86	.....	$2.39	.....	.....
Ratio of total cost to sum of items above given	1.00	.....	1.13	.....	$1.06
Total estimated cost, including engineering and contingencies	...	$4.37	.....	$3.10	2.85
Fair value to use is estimate on which 14% for engineering and contingencies is to be added	...	3.85	.....	2.72	2.50

*The contract price at ordinary depths of cut, and exclusive of rock, was 70 cts. per lin. ft. The difference, 78 cts. per ft., represents the additional allowances for extra depth and for rock and for tunnel, and for all contingencies because of the character of the ground. These additional costs would naturally be somewhat higher on the 26-in. line than on the 24-in. line, and the route of the 20-in. line covers substantially the same space as that occupied by both the 26-in. and 24-in. lines.

lined supply main was laid from the lake to the city. The upper portion of this, approximately 3½ miles in length, was 26 ins. in diameter; the lower portion, approximately 11.4 miles in length, 24 ins. diameter. The actual cost of this compound main was fortunately developed from the books of the company and is given in Tables VIII and IX, as some of the unit costs to be derived therefrom are interesting and valuable.

It should be stated that the static pressures upon this supply main are approximately as follows:

4 miles,	under	0— 40 lbs. per sq. in.
2.7 miles,	under	40— 60 lbs. per sq. in.
4.9 miles,	under	60— 80 lbs. per sq. in.
2.3 miles,	under	80—100 lbs. per sq. in.
0.9 miles,	under	100—120 lbs. per sq. in.

The main is stated to have been built with a factor of safety of approximately 3, but the computation of the factor of safety under several assumed heads indicates that the actual factor of safety is probably not in excess of 1.5 at the points of maximum pressure, assuming always static pressures, and ignoring alike the decrease in pressure due to friction and the increase in pressure due to water hammer or other causes.

The cost of this 26-in. pipe line was excessive, owing to deep cut work, a considerable amount of which was in quicksand.

Mr. Allen Hazen, who was one of the engineers retained by the Water District in the valuation of the Portland waterworks, made the interesting analysis of these items of cost given in Table X.

Cost of Lining Iron Service Pipes With Cement.—Mr. Fayette F. Forbes gives the following relative to lining wrought iron service pipes with cement. The pipe is bought in short lengths, 16 ft., and is 1 to 2 ins. diam. before lining. The lining reduces the diameter a little less than ¼ in. Such pipes have given perfect satisfaction for 25 years in Brookline, Mass. In 1900 the cost of lining a 1-in. pipe was 1½ cts. per ft.; a 2-in. pipe, 3 cts. per ft. A gang of 6 men will line 4,000 to 5,000 ft. of 1-in. pipe per day. The gang is as follows:

1 man mixing cement.
1 man filling press and overseeing.
1 man working pipes to the press and from the press to the coning frames.
2 men (one at each end of pipe) doing the coning.

In 1898 the cost of labor and cement for lining 9,000 ft. of 1-in. and 3,000 ft. of 2-in. pipe was as follows:

Labor:	
Preparing pipes	$65.79
Cementing	66.65
Grouting	22.66
Reaming	39.98
Materials:	
23 bbls. natural cement at $1.10	25.30
Coal for heating shop	6.00
Grand total	$226.38

Which gives 1.5 cts. per ft. for lining the 1-in. pipe, and 3.03 cts. per ft. for the 2-in. pipe.

A barrel of cement will line and ground the following lengths:

1-in. pipe, 700 ft.

1¼-in. pipe, 500 ft.

2-in. pipe, 300 ft.

Extreme care must be used to get uniformly good results. The following methods are best: Use wrought iron pipe in 16 ft. lengths. Straighten all bent pipes. Remove couplings, turn them around and screw on the other end, to avoid trouble in putting lengths together. Examine for defective welds. Run a cutting tool through pipe to remove scale, dirt, and projections of iron from the welds. Use American natural cement for lining (Portland is too heavy), and use it neat. Sift all cement to remove pieces of unground rock, wood, paper, etc. Use cement quickly after wetting. One man mixes cement and water, preparing only enough for 6 pipes at a time, and constantly working it over to keep at right thickness. If any of the batch is left over, throw it away. The pipes are filled full of the cement mortar, using a press made by the Union Water Meter Co., of Worcester, Mass., who also make the cones and other tools. Cones are passed through the pipe twice, and the cement that is pushed out is used in the next pipe, except that from the last pipe filled by the batch of cement, which is thrown away. While the cone is being drawn through, the pipe is slowly revolved to keep the cone as nearly in the center of the pipe as possible. However, results are satisfactory even if the lining is quite uneven in thickness. The cones are washed after each pipe is lined. Before the cones are drawn through, a piece of pipe 12 to 18 ins. long is screwed to each end of the pipe to be lined, to ensure a perfect lining at the ends. After the pipes have been lined 3 to 5 days, until the cement is quite hard, a thin grout of cement is run through them, by elevating one end of the pipe and pouring the grout in. A rubber cone is then drawn through, leaving a smooth, impervious lining. The ends of the pipe are then reamed out to fit the composition ferrules, and the threads are cleaned. Ferrules are made of best steam metal, ⅝-in. diam. on the inside (for a 1-in. pipe). Double ferrules are used where pipes are screwed together, and single ferrules for connections at the main. These pipes can be bent without damage to the lining, if care is used.

Cost of Setting Meters and Laying Service Pipes.*—Mr. W. H. Shillinglaw gives the cost of setting water meters during 1908 by the Water Works Department, Brandon, Manitoba, as follows:

Crown meters	⅝ in.	¾ in.	1 in.	1½ in.
No. of meters set	499	20	5	2
Cost of labor	$295.85	$20.55	$5.97	$2.60
Cost per meter	0.593	1.02	1.20	1.30
Cost of materials	145.73	10.24	1.84	.....
Cost per meter	0.282	0.51	0.37	.....
Total cost per meter	0.875	1.53	1.57	.....

**Engineering-Contracting*, Jan. 20, 1909.

These meters were all set in basements by day labor by city employes. The cost for ⅝-in. meters varied from 20 cts. to $2 for labor. A large number of these meters were installed on old services and entailed considerable alteration in service pipes and additional expense. The cost of setting meters on new services varied from 20 cts. to 50 cts. for labor.

The cost of laying water service pipes during 1908 was as follows:

	½ inch.	¾ inch.
No. of services	92	7
No. of feet laid	3,051	290
Cost of labor	$1,030.73	$ 96.69
Cost per ft.	0.34	0.333
Cost per service	11.38	13.81
Cost of supplies	857.38	121.90
Cost per service	9.32	17.41
Average length of service, feet	33	41

These services were laid in 10-ft. trenches in sand, gravel, some dry and a considerable number very wet and requiring pump-

CITY ENGINEER'S OFFICE.

Brandon, *June 23*, 1908.

I beg to report the following labor and material used in

installing / repairing .... *New Service* .... for Premises ....

No .... *16th* .... Street

for Mr .... *Giddings & Wyman* .... Ser. No .... *1162* ....

Installed by .... *Walker* ....

			$	
Labor		*13½* hrs. at *25*	$ *3*	*.37*
		69 hrs. at *17½*	$ *10*	*.32*
Length of trench		*44* ft.		
Materials				
	44 ft.	in. *½* lead pipe	$ *6*	*.16*
	ft.	in. lead pipe		
	ft.	in. iron pipe		
	ft.	in. iron pipe		
	1	*½* in. Corp'n Cocks		*.99*
	1	*½* in. Kerb Cocks	*1*	*.85*
	1	Service Box	*1*	*.87*
		in. Unions		
		in Elbows		
		in. Check Valve		
½ in. Lead Pipe 6 lbs. per yd.				
¾ in Lead Pipe 10 lbs. per yd.				
			$ *24*	*.56*

Signed .... *Wm. Smith, Per R. M* .... Foreman.

Fig. 6. Blank for Reporting Cost of Setting Water Meters.

ing. Refilling was well rammed. The cost of labor includes making up service, tapping main, etc. All work was done by day labor by city employes. The cost of labor varied from 26 to 50 cts. per lin. ft. The ¾-in. services were all made up for two ½-in. branches to serve two premises.

The form employed for reporting costs is shown in Fig. 6; this form was used for both services and meters, the foreman simply filled in the proper words.

Cost of Meters and Setting, Cleveland, O.—Mr. Edward W. Bemis gives the following relative to the cost of setting ⅝-in. Trident meters in Cleveland, Ohio, during 1903. Some 20,000 meters of this size had been set during 1902 to 1903 inclusive. A ⅝-in. meter costs $6.50, and the cost of setting 13,400 meters in 1903 averaged $6.87, making a total cost of $13.37. These meters were set as follows:

857 meters in brick vaults.
3,174 meters in basement settings.
9,378 meters in sewer pipe settings.

The cost of these different types of settings was as follows:

Sewer Pipe Setting.

4 ft. of 15 in. sewer pipe	$1.46
Frost cover	0.18
Ring and cover	1.42
2 ells	0.12
2 couplings	0.08
7 ft. of ¾-in. pipe	0.35
Labor	4.01
Total	$7.62

Basement Setting.

Brick	$0.12
Cement	0.05
Cover	0.30
Fittings	0.25
Labor	3.23
Total	$3.95

Brick Vault Setting.

350 brick	$2.45
1½ sacks cement	0.38
2 couplings	0.08
2 ells	0.12
1 nipple	0.06
1 union	0.24
1 ring and cover	3.21
Labor	2.92
Total	$9.46

One meter reader is employed for every 1,000 meters, and he is accompanied by a laborer, when reading meters, to turn off the water where there appears to be waste, while the meter reader waits at the meter to detect running water. Each meter is read every 6 weeks from Mar. 1 to Dec. 1. The cost of operation per meter was as follows in 1903:

Interest and depreciation, estimated at 8% of $13.37	$1.07
Reading meters and clerical work	1.10
Total	$2.27

The prices of meters were:

⅝-in. meter	$6.50
¾-in. meter	9.45
1-in. meter	13.50

The gang for basement setting is composed of 4 meter setters (at 27½ cts. per hr.), and 4 laborers (at 21 cts. per hr.), and a horse and vehicle with driver (at 30 cts.), under a foreman (at 42 cts.). These men work in pairs, 2 men at each meter, and set a meter in 4 hrs. on the average, the range being 1 to 6 hrs., depending on the arrangement of the plumbing, etc. The opposition of plumbers to the use of laborers and meter setters was overcome by employing plumbers to wipe all lead joints. The cost of setting meters in 1907 was as follows:

	No. set.	Av. cost.
⅝-in. meter in basement	2,929	$ 4.22
⅝-in. meter on sewer pipe	1	5.00
⅝-in. meter in brick vault	4,368	13.47
¾-in. meter in basement	14	6.44
¾-in. meter in brick vault	9	18.01
1-in. meter in basement	50	7.13
1-in. meter in brick vault	37	15.71
1½-in. meter in basement	10	7.94
1½-in. meter in brick vault	10	24.42
2-in. meter in basement	6	9.96
2-in. meter in brick vault	27	21.97
3-in. meter in basement	3	30.71
3-in. meter in brick vault	10	31.36
4-in. meter in basement	2	23.83
4-in. meter in brick vault	8	46.78
6-in. meter in brick vault	1	58.01

Cost of Setting Meters and Maintenance, Rochester, N. Y.—Mr. George W. Rafter gives the following relative to the cost of setting and resetting meters and their maintenance in Rochester, N. Y. The cost of setting 11,500 new meters, during 1893 to 1905, averaged $3.24 per meter, although there were many years when the average was $2.25 or less. The cost includes the proportionate part of the salary of superintendent and meter clerk, and, as the average was only 800 new meters set per year, this element of cost would naturally form a large percentage of the total.

About once in 12 years a meter has to be removed and repairs made. The cost of removing, repairing and resetting 11,000 meters averaged $4.80 per meter, which is equivalent to about 40 cts. per year per meter. This does not include the cost of current maintenance and inspection of meters in place, which averaged 37 cts. per meter per year for 12 years, although during the last 6 years it averaged only 14 cts. per meter per year, the year of 1904 being only 9 cts. per meter.

The first cost of each meter appears to have been about $10. From this it appears that repairs and resetting have averaged 7.7% (77 cts.) of the first cost of each meter per year.

During the year 1905, there were 36,100 meters in use in Albany, Kansas City, Lowell, and Rochester, and 4,100, or 11%, of these were removed, repaired and reset.

Cost of Operating and Maintaining Meters, Reading, Pa.*—The cost of operating and maintaining the meter system of Reading, Pa., for the fiscal year ending April, 1908, was $3,568.12, for an average of 2,012 meters in service. This is at the rate of $1.77 per meter per year; in the preceding fiscal year the rate was $1.75 per meter. The unit costs for the several sub-divisions of operation and maintenance are given by Mr. Emil L. Nuebling, superintendent and engineer of water works, as follows:

Repairs	$0.878
Clerical service	.553
Reading	.193
Delivering bills	.087
General test	.039
Sundry work	.015
Stationery, etc.	.009
Total	$1.774

The cost of repairs increased 84 per cent over the previous year, due principally to extensive repairs to large meters. All other costs were lowered considerably.

Cost of Placing Hydrants, Chicago.† — The standard hydrant adopted by the city of Chicago is the Creiger; it constitutes about 80 per cent of the total number of hydrants in use in that city. These hydrants are made by the city at its own shops. The following data relate to the placing of several double hydrants of the above type, the work being done in 1906 by city forces. The costs include excavating for the connection with the main, excavating for the hydrant base, placing hydrant, backfilling, and making the connections. The trench as a usual thing averaged about 5 ft. in depth. The wages of labor per 8-hour day and cost of materials were as follows:

	Per day.
Assistant foreman	$3.62
Timekeeper	3.50
Calker	3.00
Laborers	2.50

Double teams were hired at the rate of $4.50 per day. Single teams were usually furnished by the city and charged for at the rate of $1 per day.

The prices paid for materials were as follows:

Pipe, 6 in.	49c per lin. ft.
Lead	6½c per lb.
Gaskets	5c per lb.
Coal	¼c per lb.
Special castings	2½c per lb.

The coal was used in the furnace for melting the lead for the joints.

**Engineering-Contracting*, Oct. 21, 1908.

†*Engineering-Contracting*, April 24, 1907.

Hydrant at Commercial Ave., N. E., and 83d Pl.:

Labor:	Total.
1 Assistant foreman	$ 3.62
¼ Timekeeper	.87
2 Calkers	6.00
6 Laborers	15.00
1 Single team	1.00
Total labor	$26.42
Material:	
Pipe, 12 ft. of 6 in.	$ 5.88
50 lbs. lead	3.25
Gaskets	.10
Coal, 50 lbs.	.12
Specials, 220 lbs.	5.50
Total material	$14.85
Grand total	$41.27

The excavation was in clay, which was hard digging.

Hydrant at 21st St., between Blue Island and Ashland Aves.:

Labor:	Total.
Assistant foreman	$ 3.62
Calker	3.00
11 Laborers	27.50
Total labor	$34.12
Material:	
Pipe, 14 ft. 6 in.	$ 6.86
Lead, 90 lbs.	5.85
Gaskets	.25
Coal, 100 lbs.	.25
Specials, 237 lbs.	5.92
Total material	$19.13
Grand total	$53.25

The excavation was in clay, and was hard digging.

Hydrant at Rosemont Ave., 140 ft. south of Clark:

Labor:	Total.
Assistant foreman	$ 3.62
¼ Timekeeper	.87
2 Calkers	6.00
5 Laborers	12.50
Double team	4.50
Total labor	$27.49
Material:	
Pipe, 32 ft. 6 in.	$15.68
Lead, 70 lbs.	4.55
Gaskets	.15
Coal, 25 lbs.	.06
Total material	$20.44
Grand total	$47.93

The excavation was in sand, which was easy digging.

Hydrant at northeast corner 24th Pl. and Stewart Ave.:

Labor:	Total
2 Calkers	$ 6.00
6 Laborers	15.00
½ single team	.50
Total labor	$21.50

Material:

Pipe, 38 ft. 8 in	$18.62
Leau, 180 lbs.	11.70
Gaskets	.50
Coal, 150 lbs.	.37
Specials, 543 lbs.	13.57
Total material	$66.26
Grand total	$87.76

The excavation was in clay, which was hard digging.

Hydrant at Winona and Winchester Ave.:

Labor:	Total.
¼ Timekeeper	$ 0.87
Calker	3.00
3 Laborers	7.50
½ Single team	.50
Total labor	$11.87

Material:

Pipe, 5 ft. 6 in.	$ 2.45
Lead, 30 lbs.	1.95
Gaskets	.05
Coal, 25 lbs.	.06
Specials, 290 lbs.	7.25
Total material	$11.76
Grand total	$23.63

The excavation was in sand, and was easy digging.

Cost of Concrete Vaults for Valves.*—Mr. Carroll Beale gives the following:

The system of concrete construction for valve casing foundations described and illustrated here has been in successful operation in the District of Columbia for nearly a year. The foundation, Fig. 7, consists of concrete rings 3 ft. in diameter, 8 ins. and 4 ins. high, 3 ins. thick and reinforced with 16-gage expanded metal. These rings have proven to be not only more economical than the old brick construction, but the department is now enabled to build a foundation in fiv minutes, whereas with the brick construction one whole day wa. required by a bricklayer and his force to construct a foundation 4 ft. deep.

To illustrate the economy of these rings, take for example a masonry foundation 4 ft. deep of brick. This required the services of a bricklayer and force one day of eight hours. The bricklayer's force account and material used were as follows:

1 bricklayer at $5 per day	$ 5.00
2 laborers at $1.75 per day	3.50
Cart and driver $2.25 per day	2.25
420 red brick at $9 per M	3.78
¾ bbls. of Portland cement at $1.79	1.31
⅓ cu. yd. sand at $1.20	0.40
Total	$16.24

**Engineering-Contracting*, Nov. 18, 1908.

For a 4-ft. foundation of concrete, six 8-in. rings are required. These rings in place cost 50 cts. each; therefore the cost would be $3, as against $16.24 for the brick construction. It is therefore demonstrated that the cost of the concrete foundation is less than 20 per cent the cost of the old brick construction, not taking into consideration the time lost by the bricklayer in moving about the city.

The ring, 8 ins. high, cares for a height formerly occupied by

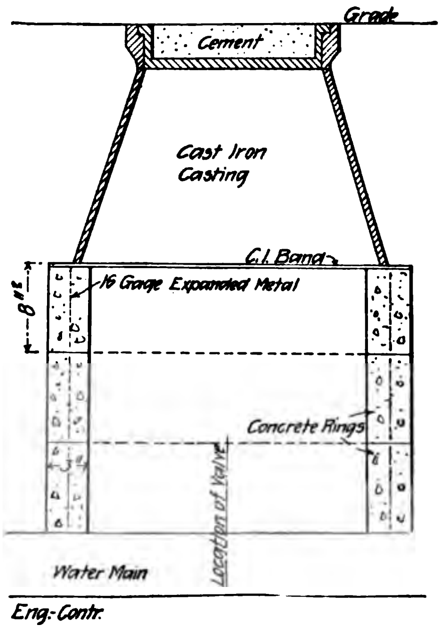


Fig. 7.—Concrete Vault.

6 sq. ft. of brickwork 9 ins. thick, or 72 brick, which at $9 per M is equal to 65 cts., so it may readily be seen that the cost of these rings is less than the cost of the brick alone without mortar and without labor, which last item amounted to $10.75 per day current expense.

An itemized cost of the rings is as follows:

0.0767 bbl. of cement = 1/13 bbl.

0.048 cu. yd. gravel = 1/20 yd.

0.024 cu. yd. sand = 1/40 yd.

The cost of one ring therefore is:

	Cts.
Concrete	25
Labor	7
Steel	16
Total	48
Placing	2
Total for ring in place	50

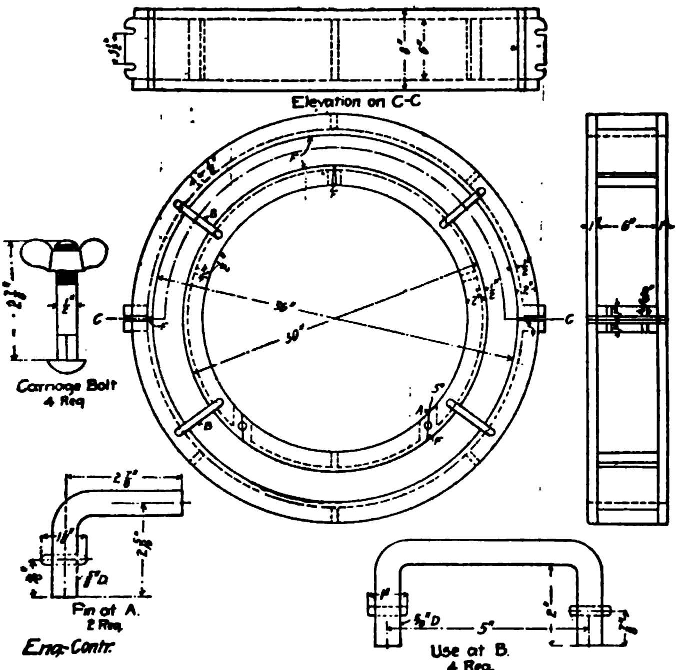


Fig. 8.—Cast Iron Forms.

To sum up the relative merits of the brick and concrete construction the use of concrete saves the department a current expense of $10.75 per day, avoids the delays attending brick construction, is as readily removed as the brick, and is much stronger.

These rings are made in the cast-iron forms shown by Fig. 8, on a smooth platform, and one man is able to make four 8-in. rings in one hour.

As illustrative of the economy in reinforced concrete vault construction, the accompanying drawings, Figs. 9 to 11, and Table XI, give examples of the types of vaults now being constructed in the

District of Columbia. Three of these vaults, 5 ft. 10 ins. by 5 ft. 6 ins. by 11 ft. 7 ins., 5 ft. 9 ins. by 5 ft. by 9 ft., and 6 ft. 2 ins. by 8 ft. 10 ins. by 6 ft., have just been completed at New Jersey Ave. and B St., just north of the United States Capitol, at a cost of $50 each, excluding the cost of the lumber which will be reused. The roofs of these vaults have an ultimate strength of about 3,500 lbs. per sq. ft., and the flat construction permits of at least 2 ft. more

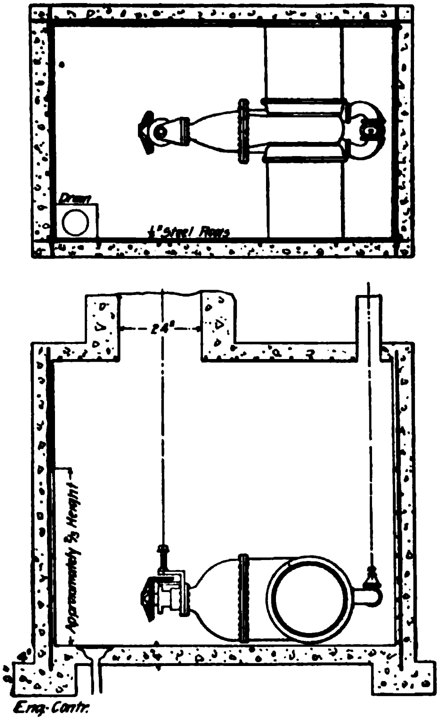


Fig. 9.—Concrete Vault for Horizontal Valve.

head room than can possibly be had where a brick arch is used. This last is a very important item where the mains are shallow and where every inch of head room counts. The vaults may be constructed for approximately one-third the cost of the brick vaults and have a much greater factor of safety than the old brick vaults using 13-in. walls. The drawings and tables explain fully the method of construction without further description.

Cost of Dipping Pipes.—In a very interesting article by Thomas

TABLE XI.—SHOWING DIMENSIONS AND QUANTITIES FOR REINFORCED CONCRETE VAULTS FOR HORIZONTAL VALVES, WASHINGTON, D. C.

Size of Valve, Ins.	Depth to Bottom of Main, ft.	Nominal Dimensions of Vault, Inside, ft.	Height of Vault Inside, ft.	Thickness of Roof, ins.	Thickness of Walls, ins.	Spacing C. to C. of Rods in Roof, ins.	Spacing of Horizontal Rods in Walls. Long Span.	Spacing of Horizontal Rods in Walls. Short Span.	Spacing of Vertical Rods, ins.	Cu. Yds. of Concrete.	Cu. Yds. of Sand.	Cu. Yds. of Gravel.	Bbls. of Cement.	Cu. Yds. of Excavation.	Horizontal Rods in Walls. Long Span. No.	Horizontal Rods in Walls. Long Span. Lnth, Feet.	Horizontal Rods in Walls. Short Span. No.	Horizontal Rods in Walls. Short Span. Lnth, Feet.	Rods in Roof. No.	Rods in Roof. Lnth, Feet	Vertical Rods. No.	Vertical Rods. Lnth, Feet.
20–24	5	8 x 5	4	4½	5	5½	....	....	....	4¾	2	3¾	6	10½	....	....	....	....	18	6	....	....
20–24	6	8 x 5	5	4½	5	5½	24	33	24	5	2½	4½	6½	13	66	9	6	6	18	6	15	7
20–24	8	8 x 5	6½	5	5½	4½	18	25	20	6½	2¾	5	8	16	10	9	8	6	21	6	18	9
20–24	10	8 x 5	6½	5	6	4½	12	17	16	7¾	3¼	6½	10	20½	16	9	12	6	21	6	22	11
20–24	12	8 x 5	6½	5½	6	4	10	14	12	9¼	3¾	7½	12	25	22	9	16	6	24	6	29	13
30–36	6	11 x 5	5	5	6	4½	18	33	24	6¾	2½	5¼	8¼	16	8	12	6	6	30	6	18	7
30–36	8	11 x 5	6½	5	6	4½	16	21	20	8	3½	6½	10¼	21½	10	12	8	6	30	6	22	9
30–36	10	11 x 5	6½	5½	6	4	12	16	16	10¼	4½	8½	13¼	26½	16	12	12	6	34	6	27	11
30–36	12	11 x 5	6½	5½	6½	4	10	13	12	12¾	5½	10½	16¼	31½	20	12	14	6	34	6	35	13
30–36	14	11 x 5	6½	6	7	4	8	10	11	14½	6	12	18¼	36½	30	12	24	6	34	6	41	15
48	8	13 x 6	6½	6	6	4	14	28	20	10	4½	8½	13	30	10	14	8	7	39	7	25	9
48	10	13 x 6	6½	6	6	4	10	20	16	12¼	5	10	16	37½	18	14	10	7	39	7	31	11
48	12	13 x 6	6½	6	6	4	8	16	13	14¾	6	12	18½	44½	26	14	14	7	39	7	37	13
48	14	13 x 6	6½	7	7	7	6	10	10	16¾	7	14	22	52	40	14	24	7	45	7	43	15
48	16	13 x 6	6½	7	7½	3½	6	9	8	19¼	8	16	25	60	48	14	30	7	45	7	50	17

H. Wiggin, in the Journal of the Association of Engineering Societies, 1899, Vol. 22, on the Manufacture and Inspection of Cast-Iron Pipes, the following data are given as to the cost of dipping pipes. To coat one 12-ft. length of 48-in. cast-iron pipe costs approximately as follows for different coating materials:

3¾ gals. crude tar at $3 per bbl. of 52 gals.	$0.22
5 gals. pitch at $5 per bbl. of 52 gals.	0.50
1½ gals. tar varnish at 10 cts.	0.15

The first two are applied by dipping, but the tar varnish is applied with a brush.

Rusty pipes will not hold a coating.

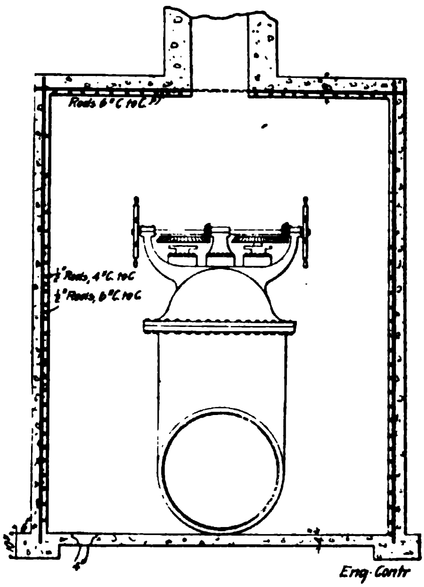


Fig. 10.—Concrete Vault for Vertical Valve.

Cost of Cleaning Water Pipe, Pittsburg, Pa.—Mr. J. D. Underwood gives the following: An 8-in. cast-iron water pipe at Pittsburg became coated with 0.32 in. of scale during 14 yrs. of use so that the pressure at the end was 34 lbs. below the theoretical static head. The contract price for cleaning 3,300 ft. of pipe was 24 cts. per ft., at which price the contractor made a very large profit, as will be seen from the following data.

The pipe was cleaned in lengths averaging about 800 ft., the range being 400 to 1,200 ft., depending on local conditions. The pipe was cut at intervals of 800 ft. (average), and a special Y

connection inserted, into which the cleaner could be introduced. These special Ys are so made that a cover can be bolted to them, should an emergency arise necessitating putting the pipe line into service. In order to get a wire cable through the pipe, a "go-devil" is first run through. It consists of two cones on an iron rod, each cone about 12 ins. long, and spaced 8 ins. apart. The cones are inserted blunt end foremost. To the "go-devil" is fastened a No.

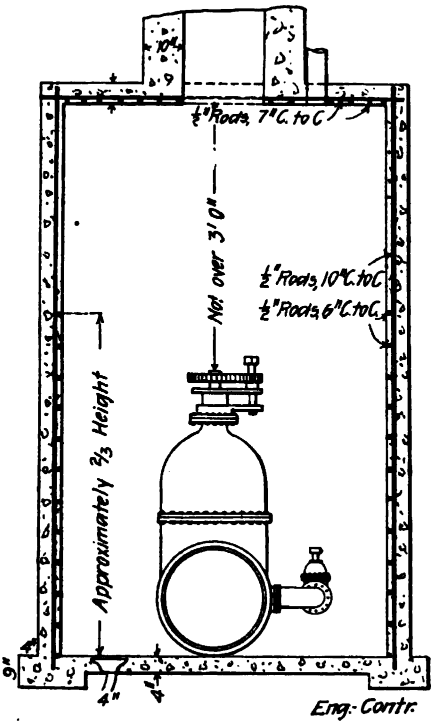


Fig. 11.—Concrete Vault for Vertical Valve.

22 flexible wire cable. The water is turned on and forces the "go-devil" through the pipe to the next special Y. The water is then shut off and a ⅝-in. wire cable is drawn back through the pipe by means of a one-man winch. The cleaner, or scraper, is fastened to the cable and is drawn through the pipe by a four-man winch, the water washing the broken scale out of the pipe ahead of it.

The time required to clean an 800-ft. section was as follows:

	Mins.
Running the "go-devil" through	3
Pulling cable through	38
Pulling cleaner through	48
Total	89

The following gang was engaged for 6 days, the wages being assumed:

	Per day.
7 laborers at $1.50	$10.50
1 mechanic	3.50
1 foreman	5.00
Total	$19.00

The labor, therefore, cost less than $120 for 3,300 ft. cleaned, or less than 3.7 cts. per ft. It is stated that even this cost could have been cut almost in two had it been possible to shut off the water continuously, but, as the pipe line was the main source of water supply for a considerable district, the water had to be turned on at intervals, delaying the work 2 or 3 days.

Cost of Cleaning Water Pipe, Halifax.—Mr. E. H. Keating gives the following costs of cleaning water pipes in 1881 at Halifax, Canada.

A 24-in. main, 19 yrs. in use, and 13,400 ft. long, was cleaned for 4.4 cts. per ft., the items being:

Labor	$121
Materials, including scraper	333
Manholes of brick and stone	139
Total	$593

A 20-in. main, 13 yrs. in use, and 6,000 ft. long, was cleaned for 5.4 cts. per ft., the items being:

Labor	$ 85
Materials, including scraper	193
Manholes of stone	48
Total	$326

A 15-in. main, half 13 yrs. and half 25 yrs. old, 29,500 ft. long, was cleaned for 1.7 cts. per ft., the items being:

Labor	$248
Materials, including scraper	162
Manholes	84
Total	$493

A 12-in. pipe, 19 yrs. in use, 3,700 ft. long, was cleaned for 4.9 cts. per ft., the items being:

Labor	$ 34
Materials (not including scraper, but including 2 batch boxes)	50
Manholes	99
Total	$183

All told, some 62,800 ft. of 24, 20, 15 and 12-in. pipe were cleaned at a cost of $1,769, or 2.82 cts. per ft., not including cost of man-

holes, which amounted to $430, or 0.7 ct. per ft., additional, making a total of 3.52 cts. per ft.

Manholes and "batch boxes" were built at intervals to insert the cleaners, which were scrapers provided with pistons, driven through the pipes by water pressure.

The incrustation on the pipes was ⅝ to 1¼ ins. thick.

Cost of Cleaning Water Pipe, St. John, N. B.—Mr. Wm. Murdoch gives the following relative to the cost of scraping water pipe at St. John, N. B., in 1897:

Special iron "hatch boxes," were made, consisting of short lengths of cast-iron pipe, provided with a flanged opening and a flanged cover, bolted together. Through the "hatch," or opening, the scraper was inserted or removed. There were 9 "hatch boxes" in 4.3 miles of 24-in. pipe. Each box weighs 3,300 lbs. and costs $167. Hence the first cost of these hatch boxes was $350 per mile of pipe, or nearly 7 cts. per ft.

The scraper weighs 263 lbs., and consists of an iron shaft about 6 ft. long, made of a 3-in. wrought-iron pipe, at the front end of which is the scraper, and at the other end a "piston"; there is a second piston at the middle of the shaft. The scrapers are 12 steel blades, arranged in two sets of six each, one set back of the other on the shaft. The blades are bent back and are springy enough to pass over such obstructions as cannot be removed. This scraper cost $40. It was forced through the pipe by the water pressure. To remove an incrustation about ¾ in. thick required 22 trips of the scraper, and the labor cost of cleaning the 4.3 miles of 24-in. pipe was $64 per mile, or 12 cts. per ft. The working force consisted of:

6 men (at the valves).
1 mechanic.
2 men (watching scraper).
2 teams.
1 foreman.

The teams were used to transport the men and the scraper back to the starting point. The laborers were stationed, 2 each, at the valves close by the flushing stations.

The 2 men who watched the progress of the scraper through the pipe could do so by listening to the noise that it made.

Cost of Cleaning Water Pipe, Boston, Mass.—Mr. Dexter Brackett gives the following relative to the cost of scraping pipes in Boston in 1886. Tubercles ⅝ to 1¼ ins. thick were removed. The pipes were not supply mains but distributing pipes, 6 and 12 ins. diameter. Nearly 4 miles of 12-in. pipe were cleaned for 15.6 cts. per lin. ft., and 12 miles of 6-in. pipe for 9 cts. per ft., not including 5 cts. royalty per ft. paid for the use of the scraper. The scraper is a flexible center shaft, 3½ ft. long, composed of coiled steel springs, connecting small castings, to which are hinged two sets of steel scrapers arranged radially around the shaft about 12 ins. apart. These scrapers are held against the sides of the pipe by coiled springs. Back of the scrapers are two rubber pistons, 2 ft. apart, so as to insure water pressure on the machine when passing

branches. No "hatch boxes" were used, as above described, but a section was cut out of the pipe, every 1,000 ft., and the scraper inserted. The section was replaced, clamp sleeves being used, and lead joints poured. The water, at 30 lbs. pressure, forced the scraper through the pipe. In some cases the displaced rust was forced into the service pipes, but this was removed by applying a force pump to the house plumbing and forcing the rust back into the main. In a test of a section of 6-in. pipe that had been laid 38 yrs. the discharge was doubled by the removal of the tubercules or rust.

Cost of Water Pipe Maintenance.*—The diagram, Fig. 12, and Table XII, give some interesting data on the percentage variations in cost of maintenance, labor and cast-iron pipe for the water pipe systems of Chicago, Ill., for the period from 1895 to

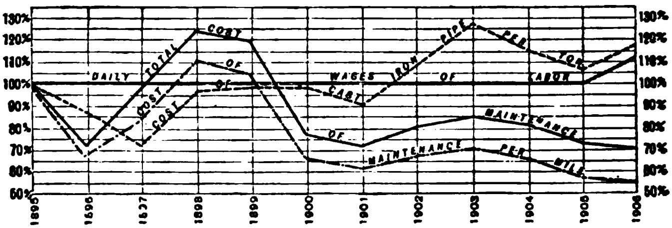


Fig. 12.—Cost of Pipe Maintenance.

1906. The data were compiled by the Division of Water Pipe Extension, Mr. W. A. Devering, superintendent.

TABLE XII.

Year.	Total Mileage of Pipe.	Average Cost of Maintenance Per Mile.	Percentage Variation of Average Cost of Maintenance Per Mile.	Cost of Cast-Iron Pipe Per Ton.	Percentage Variation in Cost of Pipe.	Daily Wages of Laborers.
1895........	1612	$217.09	100.0	$26.00	100.0	$2.25
1896........	1691	149.28	68.7	23.00	88.4	2.25
1897........	1730	183.68	84.6	19.00	73.0	2.25
1898........	1801	240.89	110.6	25.00	96.1	2.25
1899........	1816	226.95	104.5	25.50	98.0	2.25
1900........	1872	144.04	66.3	25.50	98.0	2.25
1901........	1890	132.59	61.1	23.50	90.4	2.25
1902........	1918	144.27	66.5	28.00	107.7	2.25
1903........	1939	151.83	69.9	33.00	126.9	2.25
1904........	1978	141.73	65.3	30.00	115.4	2.25
1905........	2038	123.66	56.9	27.50	105.8	2.25
1906........	2073	117.37	54.0	30.00	115.4	2.50

*_Engineering-Contracting_, July 24, 1907.

Cost of Hydrant Maintenance in Winter.*—The accompanying table, abstracted from the report of Metcalf & Eddy, engineers, Boston Finance Commission, shows the cost of hydrant maintenance in Boston, Mass., and in neighboring cities, from the best information available, giving both the estimated total cost and the costs per hydrant. The figure for Boston represents the actual cost as charged upon the books of the department. The costs for the other cities are estimated on the basis of the best information that could be obtained as to methods, wages and duration of work.

Cost of hydrant maintenance in winter in Boston and other New England cities:

City.	No. Hydrants.	Total Cost.	Cost per Hydrant.
Boston, Mass.	7,772	$19,643	$2.53
Cambridge, Mass.	1,046	2,496	2.39
Chelsea, Mass.	319	468	1.47
Worcester, Mass.	2,012	2,574	1.28
Lowell, Mass.	1,272	806	.63
Newton, Mass.	976	234	.24

Cost of Thawing Water Pipes by Electricity.†—On the basis of 125 house services thawed by electricity in Rutland, Vt., in February, 1904, the cost of the thawing per service was as follows:

Electricity	$1.68
Labor	1.85
Teams and drivers	0.58
Total	$4.11

On the average 17 amperes of alternating current at 2,200 volts were required, and at 10 cts. per kw.-hour the current cost was $1.68, as shown above. The average time consumed was 27 minutes.

Cost of Stop Cock Box Repairs, Etc.‡—From May 13 to December 31, 1907, the Water Department of Cleveland, O., put 9,290 stop boxes to grade, besides replacing 1,803 old boxes with new ones. In addition 330 new stop cock boxes were put in and 10 new stop cock bottoms. The cost of the work was as follows:

		Labor.	Materials.
Boxes put to grade	9,290	$0.409	.....
New boxes put in	1,803	0.839	$1.786
New tops put in	330	0.419	0.879
New Bottoms put in	10	0.842	0.920
Dug up and cleaned out	639	0.839	.....

The wages paid for labor in Cleveland in 1907 were about as follows:

	Per Hour.
Foreman	$ .42
Assistant foreman	.33
Labor	.22
Team	.50

Cost of Subaqueous Pipe Laying.—A line of 12-in. water pipe was laid in a trench dredged across a river 500 ft. wide, as follows:

**Engineering-Contracting,* Sept. 22, 1909.
†*Engineering-Contracting,* March 20, 1907.
‡*Engineering-Contracting,* Nov. 4, 1908.

The water in the river averaged 4 ft. deep and the trench was dug 6 ft. deep, making a depth of 10 ft. from water surface to bottom of the trench. The small home-made dredge, described in my book on "Earthwork," was used for the dredging. To lower the pipe into the trench A-frame bents were built of 4x6-in. timber, the legs of the bents straddling the trench, and each pipe was supported by an iron rod passing through a hole bored in the horizontal member of the A-frame. These rods were about 12 ft. long, ⅝-in. diameter, and threaded their full length. Each rod was provided with a hook at its lower end to hook into an iron ring around the pipe. The pipe was ordinary cast-iron pipe, and was leaded and calked while suspended from the A-frames. Then it was the intention to lower the 500 ft. of pipe all at one time by putting a man with a monkey-wrench at each rod, to give the nut on the rod a turn at a given signal from a whistle. There were 43 bents, 12 ft. apart, and it was decided that a force of 10 men could lower the pipe satisfactorily by giving a few turns of the nuts on 10 rods, then moving to the next 10 rods, and so on. Through carelessness or mischief, some of the men gave more turns to the nuts than the signals called for. This threw the weight of several pipes upon two or more rods, and broke one of them at the hook, which was the weak spot. Immediately all the other rods broke in rapid succession, dropping the pipe line into the river. The pipe settled to the bottom without breaking in two anywhere, and only one joint showed any leakage of air when I inspected the line immediately after the accident. This joint was calked by a man who dived down repeatedly, and struck a few blows each time he was down. However, a diver was sent for to examine every joint, and his inspection showed the pipe line to be intact from end to end. The cost of building the A-frames, placing and calking the pipe line was as follows:

10 men, 3 days, at $1.75	$ 52.50
1 foreman, 3 days, at $3.00	9.00
10 men, 1 day at work lowering pipe, at $1.75	17.50
1 foreman, 1 day at work lowering pipe, at $3.00	3.00
1 diver, 1 day inspecting line	25.00
Traveling expenses of diver	15.00
Total for 516 ft. of pipe	$122.00

The above does not include the cost of the iron rods, nor the timber used in the bents, nor the building of a small raft from which to erect the A-frame bents.

From this experience I believe it would be safe to dispense with the threaded iron rods for lowering such a line of pipe. The pipe could be held just above the water surface by small manila ropes, until calked. Then upon cutting one or two of the ropes, the rest would break and allow the pipe to settle into the water. As a 12-in. pipe line is quite buoyant, when filled with air, it settles down gently upon the bottom of the trench. In case a break should occur in the line, threaded rods could be made, and the pipe raised and repairs made at but slightly greater expense than would have been incurred had rods been used in the first place. When pipe

is lowered as above described, one flexible pipe joint is usually provided at each end of the pipe line.

Cost of Laying a Submerged Pipe Across Deal Lake, N. J.*—The following account of the methods and cost of laying 370 ft. of 6-in. cast-iron pipe across Deal Lake, between Interlaken and Loch Arbor, N. J., has been furnished us by Mr. James B. McCord, Civil Engineer, of New York City. The water in the lake at the point of crossing averages 5 ft. deep, and as the bottom is fairly uniform no dredging was necessary. The pipe was laid parallel to a line of old bridge piles and these were used as supports for a temporary platform on which the pipe was laid and connected prepara-

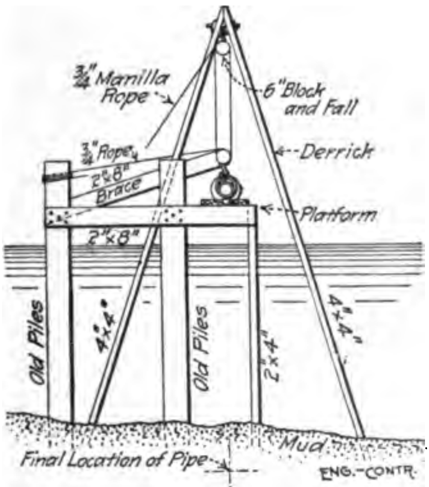


Fig. 13.—Laying Subaqueous Pipe Line.

tory to sinking. The arrangement of the platform is shown in Fig. 13.

In connecting up the pipe six ball joints were inserted at intervals corresponding to changes in profile of the bottom; all other joints were calked. After the pipe was connected, six light A-frame derricks were set astride the pipe, as shown by the sketch; these derricks were rigged with 6-in. blocks and ¾-in. rope. At intervals between the derricks 2x8-in. braces were nailed to the piles, as shown in the sketch. There were nine of these braces used and each had an iron thimble fastened to the outer end. Ropes tied around the pipe passed through the thimbles and back to the piles around which they were given several turns and fastened. The ropes at the derricks and braces being made taut, the platform was

*_Engineering-Contracting_, Feb. 6, 1907.

cut away, leaving the 370 ft. of pipe suspended from the derricks and braces. Two men were then placed at each derrick and brace, who on signal simultaneously lowered away until the pipe rested on the lake bottom. An examination of the pipe after lowering showed that it had suffered no injury. The pipe was standard 6-in. cast-iron pipe weighing 32½ lbs. per lin. ft. The itemized cost of the work exclusive of the cost of the pipe and the ball joints was as follows:

Platform.

	Per day.	Total.
1 foreman	$4.00	$ 6.00
6 laborers	1.75	22.24
Lumber at $30 per M	....	40.00
Total		$68.24

Distributing and Connecting Pipe.

	Per day.	Total.
1 foreman	$4.00	$ 4.00
6 laborers	2.00	14.48
Rent of raft	....	25.00
Total		$43.48

Calking Pipe.

	Per day.	Total.
1 foreman	$4.00	$ 4.00
6 laborers	2.00	28.96
Lead at 6¾ cts. per lb.	....	27.00
Yarn	....	0.75
Total		$60.71

Derricks, Braces and Slinging Pipe.

	Per day.	Total.
1 foreman	$4.00	$13.07
4 laborers	2.00	13.05
Rope	....	9.96
Clevis, bolts, etc.	....	6.00
Lumber	....	22.20
Total		$64.28

Lowering.

	Per day.	Total.
20 men	$2.00	$32.72

In noting the small cost of the platform it will be observed that the piling was already in place, thus cutting out an expensive item of the work. Summarizing the several items, we have the following:

	Total.	Per lin. ft.
Platform	$68.24	$0.1844
Distributing and connecting pipe	43.48	0.1175
Calking	60.71	0.1641
Derricks, braces and rigging	64.28	0.1737
Lowering	32.72	0.0884
Total for 370 ft.	$269.43	$0.7281

Cost of Laying Pipe Across the Susquehanna.—Mr. James P. Herdic gives the following data relating to laying 10-in. cast-iron pipe across the Susquehanna River, at Montoursville, Pa., a distance of 600 ft., average depth of water being 13 ft. A ⅞-in. manilla

rope was first stretched across the river, to act as a ferry line for the scows. The scows were loaded with pipe. The crew of 8 men and foreman were engaged 1 day in this preliminary work, and then laid the 600 ft. of pipe line in the next 2½ days. One ball and socket joint was used to every six ordinary joints. The pipe line was lowered between the two scows, by means of chain pulleys suspended from a heavy sawhorse that spanned the gap between the two boats. The pipe was laid in a gentle curve, bowed up stream, so as to form an arch to resist the stronger currents. This is certainly an excellent record for economic work.

On another place in the Susquehanna River, where the current was so swift that it would swamp a scow if held sidewise in the current by a cable, as above described, the following method was used: A scow was held in the current with its nose up stream, but at an angle with the current; ropes from bow and stern to the nearest shore serving to hold it. In this way the current kept the ropes taut, and the scow remained steady while the lead joints were poured. The pipe line lay across the middle of the scow, which was moved out from under each joint as fast as made. Six common joints to each ball and socket joint were used.

Cost of Laying a Submerged 6-in. Pipe, New Jersey to Ellis Island.—About 5,100 ft. of 6-in. pipe were laid from the New Jersey shore to Ellis Island under 10 to 17 ft. of water. A trench was dug 5 ft. deep by 10 ft. wide in the mud, using a clam-shell bucket. Heavy pipe, weighing 800 lbs. per length, provided with Ward flexible joints, was used. Two scows, each 26 x 80 ft., were fastened together, 6 ft. apart, and provided with two skids of 10 x 10-in. timbers 55 ft. long, leading down between the scows to the bottom of the trench. The skids could be lowered in rough weather. Two lengths of pipe were placed at one time on the skids, a derrick being used for the purpose, and then the scows were warped ahead 24 ft. The whole work occupied just a month, using a force of 10 laborers, 2 calkers and 1 diver to calk any leaks, etc. The best day's work was 516 ft. The line was tested under 80 lbs. pressure, and leaked only 5 cu. ft. in ½ hr.

Cost of Submerged Pipe Laying in Massachusetts.—In a paper entitled "Submerged Pipe Crossings of the Metropolitan Water Board," Journal of the Association of Engineering Societies, 1901, Vol. 27, Mr. C. M. Saville gives in detail the methods of laying submerged pipes and the following cost data, rates of wages and details of cost not being given. The work was done in 1897 in Massachusetts by contract, but the costs are the actual costs to the contractor, plant rental being included.

Mystic River Crossing.—Two lines of 36-in. pipe were laid in a dredged trench, 5 ft. 9 ins. c. to c. The trench averaged 8 ft. deep, in mud, and 35 ft. wide on top, and was 1,200 ft. long. A clam-shell dredge was used for most of the work, and averaged 27 lin. ft. of trench, or 250 cu. yds., per day, loading scows, which were dumped half a mile away. After the pipes were laid, the material was reloaded into the scows by the dredge, at the rate of 500 cu.

yds. per day. The cost of excavating the trench was 54 cts. per cu. yd. for the 11,000 cu. yds. The cost of backfilling was 23 cts. per cu. yd.

The river is a tidal stream, with tide fluctuations of 10 ft., and is 9 ft. deep at low water.

A pile foundation was built in the bottom of the trench to lay the pipe on. The piles were driven in bents of 2 piles per bent, bents being 12 ft. apart, and piles 6 ft. apart in each bent. They were driven 23 ft. into the mud, sawed off under water and capped with 10 x 10-in. spruce by a diver. The cost of sawing off and capping was $3 per pile.

Some of the 36-in. pipes were made with a spherical, or flexible, joint, and weighed 8,260 lbs. per 12½-ft. length, costing $24 per ton (ordinary pipe cost $18 a ton), and required 248 lbs. of lead per joint 8 ins. deep. These flexible joints were only used where the pipe line curved vertically.

Six lengths of pipe were joined together on shore, and lowered onto the pile foundation from a scow provided with two derricks. The pipes were slung from the lower chord of a light truss 75 ft. long, to which the derrick tackle was fastened. The scow was 23 x 70 ft., and the pipes were lowered over the side. On the opposite side of the scow was a smaller scow, loaded with gravel, which was fastened to the pipe-laying scow and thus served to counterweight the pipes. There was a 4-in. centrifugal pump on the scow for jetting out the trench if it become filled with mud.

To join the sections of pipe under water (every sixth pipe), a special joint was designed. The spigot end was turned smooth in a lathe to a taper, and had no head. The bell was grooved and designed for a lead joint 5 ins. deep. On shore, a spigot was temporarily inserted in a bell, and the lead joint cast; then the spigot was pulled out, leaving the lead joint in the bell. To re-make this joint under water, a diver guided the spigot to place; near the end of the truss (above referred to) was fastened a hydraulic cylinder, to the piston of which was fastened an iron rod with a hook at the end. A chain having been fastened back of the bell of the last pipe, this hook was fastened into the chain, and, when oil was forced into the hydraulic cylinder, the truss was drawn forward and the spigot forced home into the bell. Fastened to the bell was an iron collar, which guided the spigot into the bell, and also prevented the lead from being displaced by any carelessness on the part of the diver. The pipe line was tested by compressed air, and leaks were calked by divers.

The total cost to the contractor, including the pipe, which cost $6.75 per ft., was $13.25 per lin. ft. of pipe, including the pile foundation and the dredging.

Since the trench averaged 4½ cu. yds. per lin. ft. of pipe, at 77 cts. per cu. yd. for excavation and backfill, the cost of the trench was $3.45 per lin. ft. of pipe. This leaves $3.05 per lin. ft. for the remaining items: piling, lead, timber and pipe laying. If the piles were 45 ft. long, there were 7½ ft. of pile per lin. ft. of pipe, which probably cost the contractor about 10 cts. for ma-

terial and 10 cts. for labor (including the $8 for cutting off), or $1.50 per lin. ft. of pipe. At 82 lbs. of lead for the ordinary joints, the lead probably cost about 30 cts. per lin. ft. of pipe. The spruce cap on the piles probably cost about $18 per M, or 10 cts. per lin. ft. of pipe. Hence these three items would total $1.90 per lin. ft., leaving about $1.15 per lin. ft. as the cost of laying the pipe. The assumptions and conclusions in this paragraph are mine and not Mr. Saville's.

Cost of Laying a Submerged Pipe at Vancouver, B. C.*—Mr. J. Causley gives the following relative to a 12-in. main across the Narrows at Vancouver, B. C., in 1906:

There have been seven 12-in. mains placed across the Narrows at various times during the past 19 years. The last one has just been put in position, and of the method of accomplishing this the writer purposes giving a short description, trusting that it may prove of some interest, for the reason that it differed from the method usually followed (with variations to suit particular cases) in such work, viz., that of building a staging, or anchoring a string of rafts along the line to be followed, slinging the pipes over the position they are intended to occupy, jointing them up and lowering the connected line into place.

This method would not have been suitable in the cases under consideration on account of the water varying from 66 ft. deep at low tide to 75 ft. deep at ordinary high tide. The tide is very strong, running at speeds up to 8 knots per hour; also, and perhaps the most important of all, nearly the whole of the shipping trade of Vancouver, including ocean passenger and freight steamers, from 8,000 tons downwards, sailing ships towed in and out by tugs, coast steamers, rafts, coal barges, transfers towed by tugs, etc., passes through these Narrows. A system of hauling the pipes across was first put into practice by the Water Works Company, this system being greatly improved by the late City Engineer, Colonel Tracy, M. Can. Soc. C. E., and the Water Works staff.

About three years ago it was intended to place another main across the Narrows, and in the early part of 1904 a contract was made with Messrs. Robertson, Godson & Co., of Toronto and Vancouver, for the supply of cast-iron pipes for a submerged main, in accordance with the following specifications:

To be 12 ins. in diameter internally, 1 in. in thickness, lengths to lay 12 ft. each, of the best cast iron, strong, tough gray metal, cast vertically with the hub end down, the bell end to be bored spherically, and the spigot end to be turned where it fits in contact with the bored surface. To be tested to a pressure of 500 lbs. per sq. in. and hammered under pressure. To be coated with Dr. Angus Smith's preparation, or preferably with Wartz, Dove & Co.'s bitulithic solution.

The pipes were obtained from Stavely, near Glasgow, in Scotland, and weighed between 1,725 and 1,800 lbs. each.

**Engineering-Contracting*, April 22, 1908.

The half section, Fig. 14, at a flexible joint shows the latest form of the bell and spigot of a pipe. The shape of the bell has been altered from that of the earlier forms to cause the pipes to offer as little resistance as possible in sliding along the bed of the Inlet.

The pipes were delivered at Vancouver in August, 1905, but it was not convenient to place them in position till the latter part of 1906, when it was decided that they should be laid directly by the city, under the superintendence of Mr. S. Maddison, the manager

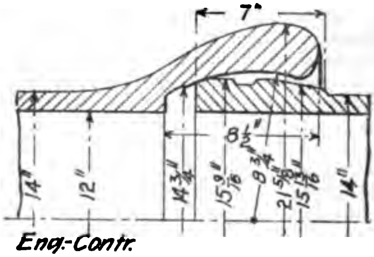


Fig. 14.—Flexible Joint.

of the water works, who had had much experience in the work of laying previous mains. Captain Westcott, who was contractor for laying two of the previous mains, and foreman on laying the steel main, was engaged as foreman of the work. This main was to take the place of No. 3 pipe line, the pipes of which were taken apart by a diver and brought to the bank.

A chute, Fig. 15, was constructed of 14-in. x 2-in. dressed plank, with 4-in. x 1-in. battens on each side—i. e., projecting 2 ins. above the plank—supported at every 6 ft. by cross pieces of 3-in. x 4-in.

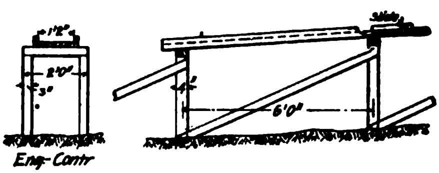


Fig. 15.—Chute.

quartering, each on 2 posts of 3 in. x 4 in., from low water on the north side of the Narrows extending back the length of the main. Each length of pipe was tested separately under a pressure of 350 lbs. to the square inch. The pipes were then placed on the chute spigot ends to the south, with a piece of 14-in. x 2-in. plank, about 2 ft. long, on the bed of the chute running between the side battens under each pipe at the bell end. The piece of plank was notched out at the top side and upper end, so as to go under, support, and steady the bell, and keep the pipe in the center of the chute. The

under skids of these blocks were well greased. The spigot of each pipe was pressed home in the bell of the next one, lead run in and calked to make a tight joint. No gaskets were used, as the bells and spigots were bored and turned to make tight and flexible joints. Each joint required from 60 to 70 lbs. of lead, making about 3½ tons of lead used in all. The pipes, after being put together and jointed, were tested collectively under a pressure of 150 lbs. per square inch.

A line was pushed through the pipes with a rod made of a number of long slats of wood nailed together and a 1¾-in. steel wire cable hauled through them.

Over the lower or south end of the string of pipes a cast-iron cap 1 in. thick, with strengthening ridges on the outer side, and flange overlapping the end of the pipe, was placed, leaded and calked. This cap had a 2-in. circular hole in the center with a stuffing-box. Through this was passed a 2-in. turned rod 3 ft. 6 ins.

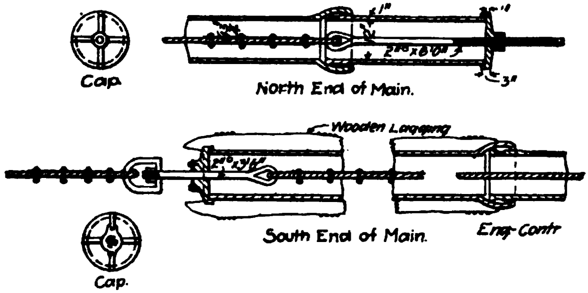


Fig. 16.—Arrangement of Hauling Cables.

long, and the hemp packing was well tightened up around it. On the inner end of the rod was an eye through which the end of the 1¾-in. steel wire cable, which went through the line of pipes, was passed, doubled back on the cable, and secured with four clips. The outer end of the eye-bar, on which a screw thread was cut, went through a stirrup-shaped ring and was made fast to it with two nuts. To this stirrup one of the hauling cables was attached and secured in the same manner as the cable inside the pipes was secured to the other end of the bar. By these means the cable had no tension on the front end of the string of pipes.

The end length of pipe carrying the cap, etc., was covered with a wooden lagging, bound at three places with ⅝-in. wire rope. Figure 16 readily explains the arrangements made.

The cable on the west side of the pipes was attached to the 40th pipe by taking two turns round the pipe, bringing the end back to the cable, and fastening it with 4 clips. The cable on the east side of the pipes was secured to the 13th pipe by means of a chain, which had a round turn round the pipe, and the ends made fast

to the cable with clips. Iron bands were put round the pipe and cables fastened at intervals to enable a fair pull to be taken.

On the upper, or north end of the pipe a cap similar to the one at the south end was placed, with the exception that the 2-in. circular hole in the center was through a plain boss. A 2-in. round bar passed through this hole. The inner end of this bar had an eye to which the cable through the pipes was attached in the same way as the other end of the cable was fastened to the bar through the cap at the south end of the pipes. On the outer end of this bar a screw thread was cut, and the cable through the pipes was tightened up with a nut. A second was placed above the first one for the sake of security. A length of 12-in. pipe, 4 ft. long, was fitted into the bell of the last pipe for the flange of the cap to fit on to. The whole was leaded and thoroughly calked. This was completed on Aug. 19.

It had taken about a month to do this work, with a gang of about seven men, under the superintendence of Captain Westcott. There were 109 pipes, making 1,308 ft. of pipes, whose weight

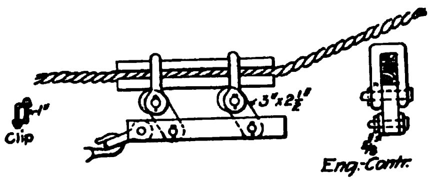


Fig. 17.—Arrangement of Gripper.

varied from 1,725 lbs. to 1,800 lbs. each, giving a total weight of about 96.05 tons. Including lead caps, internal cable, etc., the total weight would be about 102½ tons.

1,800 ft., 1½ ins. diameter, and 1,800 ft., 1¼ ins. diameter, fresh steel-wire cables had been bought. These cables were not new, but had been used for hoisting in the mines. Also four new 6-in. (circumference) 120 fathom manila ropes had been purchased at $160.00 each, for tackle. Six new 3-sheave blocks and two new single-sheave blocks had been made in the water works shops. The cables, on their reels, had been taken across to the north shore of the Narrows.

The end of a line was taken across, attached to the end of one of the cables, and the cable was hauled across, a snatch block and four horses being used. No power tackle was used, as the hauling had to be done in the space of about 15 minutes at slack water.

One cable was hauled across at slack water on Aug. 15, one on the 18th, and one on the 19th. By Aug. 23 everything was ready to begin hauling. The cables had been examined by the diver and tightened up with their blocks and tackles.

By means of a gripper, Fig. 17, to each of two of the cables was attached a tackle consisting of a pair of 3-sheave blocks with one

of the 120-fathom 6-in. manila ropes rove through them worked by a capstan to each tackle driven by one or two horses. The other cable had two tackles, with a pair of 3-sheave blocks attached to each tackle, each tackle worked by a capstan. See Fig. 18. The drum of the capstan; Fig. 19, was 18 ins. in diameter, and the lever arms 11 ft. each. The cable, however, with the two tackles attached, had been left taut too long; the flood tide caught it and carried it up channel about 100 ft. at the center, drawing two lengths of pipe slightly out of line before it could be loosened. It was necessary to draw it back to the north side and haul it across afresh. This had been done by Aug. 25, and everything found to be in order. Passing vessels had caused some inconvenience when getting the lines across.

Monday, August 27.—Hauling began at mid-day at low water with four horses, i. e., one at each capstan, and was also continued on the slack water in the evening, lasting altogether about

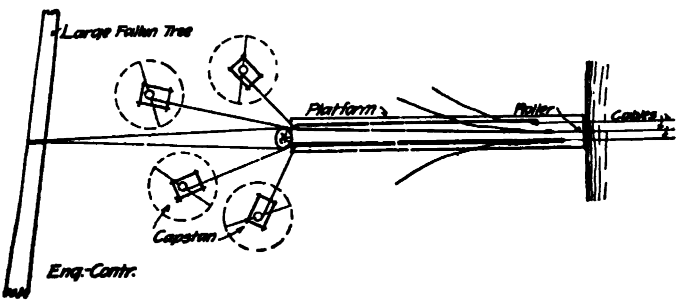


Fig. 18.—Arrangement of Capstans.

five hours, and moving the main about 178 ft. The work could not be carried on longer as the tide when stronger would have caught the cables and carried them out of line. After the first hauling the manager went down in diving dress, examined the pipes that had moved, found that they had been drawn straight, and that the joints were uninjured.

Tuesday, August 28.—Hauling was carried on from noon to 2 p. m., and from 5 to 8 p. m. The main was hauled 194 ft.; in all, 372 ft. Four horses had been used, i. e., one at each capstan.

Wednesday, August 29.—Up to 7 p. m., only about 35 ft. had been hauled. The horses had been doubled on two capstans and had not pulled well together; the tide also had not served well. Hauling was carried on from 7:10 to 7:30 p. m., when it was stopped by a signal from the other side (the light put out). It was found that one side of the chute had sunk where swampy ground was crossed, and that the pipes were slipping off. About 43 ft. had been hauled; in all 450 ft.

Thursday, August 30.—The chute was strengthened early in the

day. In the morning the tide was not favorable for hauling, which was not begun till about 6:30 p. m. Only one capstan was doubled till about 9:30 p. m., when a second horse was put on No. 1 capstan. Hauling was stopped about 1 a. m., as the horses were unable to work longer. About 300 ft. had been hauled; in all 750 ft.

Friday, August 31.—In the morning the pipe was examined by the diver, who went right along the part under water from end to end, and found everything in good order. There is a soft shingle bank extending from the north side to within about five hundred feet from the south side of the Narrows, and the pipes had

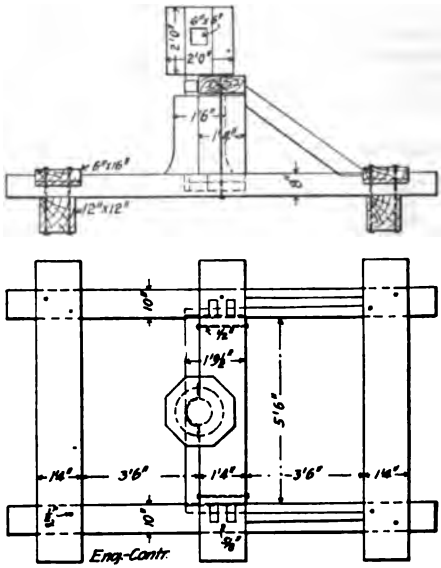


Fig. 19.—Plan and Elevation of Capstan.

ploughed into this for a depth of about two feet and moved boulders that were in their way. Further south the bottom is a sandy hardpan.

Hauling began about 5 p. m., and one fleet (the length of travel of the moving blocks, about 75 ft.) was hauled by about 7 p. m. The tackles were then overhauled. Hauling was continued again from about 8 to 8:20 p. m., when the gripper on the eastern cable gave way. It was got in order again and operations were continued. About 12:30 a. m., the central cable slipped in the gripper and work was suspended for the night. About 150 ft. hauled; in all 900 ft.

The pull was now becoming heavier.

Saturday, September 1.—The diver went down in the morning and found everything in good shape.

Hauling began about 4:30 p. m. The pipe would not start at once, and the gripper on the central cable (No. 1 capstan) slipped at about 4:45 p. m. It had to be loosened and a fresh grip taken, when the pipe was started. The fleet was finished at 6:15 p. m. It was found from measurement that 162 ft. still required to be hauled. The tackles were overhauled; a sheave in one of the blocks, which was found to be cutting (the hole had become enlarged about ¼ in.) was replaced by another, and hauling was begun again about 7:45 p. m. About 9 p. m. it was found that the head of No. 2 capstan was giving way, and work had to be suspended till a new drum could be made, 169 ft. were hauled; in all 1,069 ft.; 155 ft. remained to be hauled.

Monday, September 3.—A new capstan barrel had been made and placed in position, and hauling was begun at 8:15 a. m. The main was moved about 40 ft., but the tide was found to be running out too strongly, and work was stopped. The pull had become very heavy, as so much of the main was on the ground and part of it was coming up hill. Six horses were used this day, viz., two each on Nos. 1 and 2 capstans, and one each on Nos. 3 and 4.

Hauling was begun again at 11:10 a. m. A gripper slipped soon after starting. A fresh pin was put in and tightened up, and hauling was continued. Before long the rope of the tackle of No. 2 capstan got under the barrel of the capstan and had to be cleared. The fleet was finished at 12:25 p. m. Seventy feet still required to be hauled.

The tackle was overhauled and work begun again at 1 p. m. The rope got under the barrel of No. 2 capstan again and had to be cleared. The hauling was heavy, but the pipe moved steadily. The work was finished at 2:45 p. m., the front end of the pipe being above low water. Total distance hauled, 1,224 ft.

The main was tested on September 5, under a pressure of 125 lbs. per sq. in., and found to be perfectly tight.

Captain Westcott employed 11 men during hauling, as well as the diver and the drivers of the teams.

The cost of the 1,308 lin. ft. of submerged pipe in place was as follows:

Materials.

965.05 tons 12-in. pipe at wharf	$3,842.00
Removing to site of work	200.00
Lead, 7,000 lbs.	491.93
8,040 ft. B. M. lumber for chute, at $18	144.72
2,436 ft. B. M. lumber for platform, at $17	41.41
3 kegs nails, at $4	12.00

Labor.

Building chutes and platform, putting up capstans, placing and jointing pipe, July 2 to Aug. 11	1,002.69
Hauling pipe across the narrows (Aug. 25 to Sept. 8)	1,163.23

Miscellaneous.

Materials, provisions, cartage, incidentals, etc.	470.00
Total	$7,367.98
Plant purchased fresh	930.00
Grand total, 1,308 ft., at $6.35	$8,297.98

The above $930 worth of plant purchased for this work consisted of the following items:

2,000 ft. ⅝-in. new steel cable, at 7 cts.	$140.00
2,800 ft. 1½-in. and 1⅝-in. old steel cable	150.00
2,880 ft. 6-in. (circumference) Manila rope	640.00
Total	$930.00

This does not include the blocks.

The wages paid were high, being 25 to 30 cts. per hr. A team and driver received $8 per day; diver, $15 per day. Of the $1,163 item of hauling the pipe across the Narrows, $328 was for team and driver time.

The foregoing costs do not include the cost of taking up and removing the old pipe line, which was as follows:

Labor	$1,652.77
Materials and general expense	403.59
Total	$2,056.36

Cost of Laying Pipe Across the Willamette River.—A 32-in. pipe across the Willamette River, Oregon, was laid in 1895. Two scows and an inclined cradle were used. The gang was 16 men and 1 diver, and they laid 80 ft. of pipe per day in a trench 23 ft. below the water surface. The plant and methods are described in the Trans. Am. Soc. C. E., Vol. 33, p. 257.

Cost of a Wood Stave Pipe Line at Denver.—Mr. James D. Schuyler, in Trans. Am. Soc. C. E., Vol. 31 (1894), describes and illustrates very fully the building of a wooden pipe line for Denver, Colo. The pipe was 30 ins. diameter, made of staves of Texas pine 1¼ ins. thick, with ½-in. round iron bands. A pipe laying gang consisted of 8 to 16 men according to the number of bands per unit of length, half the gang being employed in back cinching. On a 34-in. pipe a gang placed 700 to 1,000 bands per day, laying from 150 to 300 lin. ft. of pipe. On a 44-in. pipe the rate was 500 bands per day. The cost of erection was from 5 cts. per band on a 30-in. pipe to 10 cts. per band on a 48-in. pipe. The cost of 16.4 miles of 30-in. pipe was $1.36 per ft., distributed as follows:

1,869 M Texas pine, at $27.50	$ 51,399
271,900 steel bands (½-in.) and shoes	54,300
Erection of pipe, 5.1 cts. per band, by contract	13,866
	$119,565

In addition the trenching and backfilling cost 48 cts. per ft., which was unusually expensive.

Cost of Wood Stave Pipe, Astoria, Oregon.—Mr. John Birkinbine gives the following:

An 18-in. wooden stove pipe at Astoria, Oregon, 7½ miles long, cost $0.90 per ft., in place including appurtenances, with lumber

at $35 per M and steel bands at 4.8 cts. per lb. Mr. A. L. Adams gave the details as follows: Including all appurtenances the cost was 90 cts. per ft., but it was 76 cts. excluding appurtenances. The labor cost as follows:

Building and spacing bands	55%
Back-cinching	26
Repainting iron bands	3
Backfilling to depth of 6 ins. over pipe	8.75
Placing specials	3.50
Placing air valves	0.75
Unclassified labor	3.00
Total	100.00

In Colorado, 5½ miles of 28-in. wooden stove pipe, under a head starting at 20 ft. and ending at 150 ft., cost $1.67 per ft., exclusive of ditching. The cost of 6½ miles of 36-in. to 44-in. pipe was $2.60 per ft. exclusive of ditching. The cost of 6½ miles of 36-in. to 44-in. pipe was $2.60 per ft. exclusive of ditching. In 1903 nearly 2 miles of 42-'n. wooden stove pipe was laid at Absecom, N. J., for Atlantic City, at $2.25 per ft. in place. It was laid on the hydraulic grade line, requiring no heavy banding.

Estimated Cost of Wood Stave Pipe.—In 1898 Mr. A. L. Adams made the following estimates of cost per foot of wood stave pipe in Chicago, exclusive of contractors' profits. The cost includes laying the pipe, but does not include hauling. Unfortunately the details, upon which the estimate is based, are not given. Apparently the costs do not include trenching.

Diam., ins.	25-ft. head.	50-ft. head.	100-ft. head.	200-ft. head.
12	$0.42	$0.49	$0.63	$0.85
18	0.60	0.80	1.02	1.46
24	0.79	0.91	1.14	1.61
30	0.96	1.12	1.44	2.06
36	1.19	1.40	1.82	2.65
42	1.40	1.68	2.23	3.33
48	1.55	1.85	2.46	3.67
54	2.23	2.62	3.43	5.02
60	2.85	3.35	4.37	6.40
66	3.21	3.81	5.00	7.38
72	3.65	4.38	5.83	8.73

Cost of Wood Stave Pipe Line at Atlantic City.—Mr. Kenneth Allen and Mr. C. J. Myers give the following data relative to a wood stave pipe built by contract for Atlantic City, N. J., in 1904.

The pipe is 42 ins. diameter, of Washington fir, the staves being cut from 2 x 6-in. lumber, and measuring 1 9/16 ins. thick. The bands are spaced 12 ins. apart, and are of ½ in. round steel. The bands were bent by winding them around a cylinder 38 ins. in diameter. After bending they were wired together in bunches of five, and dipped in hot (400° F.) Mineral Rubber Field Paint for about 3 mins. About 750 bands were bent and dipped per day by a gang of 7 men and a foreman, using 20 gals. of mineral rubber.

Trenching was begun Feb. 4, and the 9,800 ft. of pipe was completed Apr. 16. The material was largely sand. The pipe was

laid in the bed of an old canal, sections of which were dammed off and pumped out with two 3-in. gasoline pumps.

The pipe gang was as follows:

1 foreman.
2 men handling material.
2 men driving staves.
2 men tightening bands.
1 man rounding out pipe by hammering inside.
2 men back-cinching.
1 boy painting bands.
2 men tamping.

There were also:

2 day men on gasolene pumps.
2 night men on gasolene pumps.
2 men on diaphragm pumps.
35 men backfilling.

The first 26% of the work cost considerably more than the last 74%, due to the colder weather that prevailed in February.

The labor cost of the first 26% done during Feb. 4 to Mar. 5. was as follows, per lin. ft.:

Excavation and Backfill:	
4.92 hrs. labor at 15 cts.	$0.74
0.28 hrs. foreman at 40 cts.	0.11
Making Pipe:	
1.05 hrs. labor at 20 cts.	$0.21
0.13 hrs. labor at 40 cts.	0.05

During Mar. 5 to Apr. 16, the labor cost was as follows per lin. ft.:

Excavation and Backfill:	
4.91 hrs. labor at 15 cts.	$0.74
0.18 hrs. foreman at 40 cts.	0.07
Making Pipe:	
0.73 hrs. labor at 20 cts.	$0.15
0.07 hrs. foreman at 40 cts.	0.03

During tne first period there was less excavation per lin. ft. and less water to handle.

The freight on the staves from Washington was $300 per car. The contract price for the 42-in. pipe was $2.25 per lin. ft. exclusive of earthwork.

Labor on a Wooden Stave Pipe at Ogden.—Mr. Henry Goldmark gives the following relative to 6 ft. wood stave pipe line, 27,000 ft. long, built in 1896 near Ogden, Utah. The pipe is laid in a trench 8½ ft. wide and 9½ ft. deep. The maximum hydrostatic pressure is 50 lbs. per sq. in. The lumber was Douglas fir, the staves measuring 2½ x 8 ins. before final dressing, and 2 x 7½ ins. dressed. Sills, 6 x 8 in. x 8 ft., were laid 8 ft. apart, with 6 x 6-in. chocks or cradles on top. The bands were ⅝ to ¾ in., and there were two shoes to each band. A gang of 20 men built about 70 lin. ft. per day; 10 of these men assembled the pipe and put on enough bands to hold the staves together; the other 10 men put on the remaining bands and did the back-cinching. There were 1,500,000 ft.

B. M. of lumber and 2,500,000 lbs. of steel in bands and shoes of this 27,000 lin. ft. pipe line.

Labor on a Wooden Stave Pipe at Lynchburg.—A wood stave pipe line was laid in 1906 at Lynchburg, Va. The pipe is 30 ins. diam., made of 2 x 6-in. redwood staves, banded with ½-in. steel rods. The cast shoes weigh 1 lb. each; 320,000 bands were used for 2,000,000 ft. B. M. of staves. A gang of 18 men averaged 150 ft. of pipe built per day; 12 of these men fit up and assemble the pipe, and 6 men back cinch. The trench was 6 ft. wide, the upper part being excavated with drag scrapers.

Cost of a Reinforced Concrete Conduit.—To Mr. G. C. Woollard, engineer for James Stewart & Co., contractors, I am indebted for the following data relating to the construction of a 5-ft. concrete-steel conduit in the Cedar Grove Reservoir, near Newark, N. J. Two conduits, side by side, were built across the bottom of the reservoir from the gate house to a tunnel outlet. Since the conduits are to be submerged, a small amount of leakage at end joints is not objectionable.

Trial sections of the conduits were tested under hydrostatic pressure; one of the conduits broke under an internal pressure of 15 lbs. per sq. in., rupture taking place at a joint near the springing line of the arch where work had been stopped over night during construction. Another section, in which no stopping had occurred, resisted a pressure of 34 lbs. per sq. in.; but the leakage of the wooden bulkhead used in the test prevented applying a greater pressure.

The concrete was 1 : 2 : 5, no stone exceeding 1½ ins. being used. Expanded metal, No. 10 steel with a 3-in. mesh, weighing 0.56 lbs. per sq. ft., made by the Associated Expanded Metal Companies, was used. When construction was begun the sheets of expanded metal were bent up into the middle wall, but it was found that the inclined part of the metal acted as a screen to separate the mortar from the stone. Hence the form of the metal was made as in Fig. 20.

"The particular thing that was insisted upon by both Mr. M. R. Sherrerd, the chief engineer of the Newark Water Department, and Mr. Carlton E. Davis, the resident engineer at Cedar Grove Reservoir, in connection with these conduits, was that they be built without sections in their circumference, that the whole of the circumference of any one section of the length should be constructed at one time. They were perfectly willing to allow us to build the conduit in any length section we desired, so long as we left an expansion joint occasionally which did not leak.

"The good construction of these conduits was demonstrated later, when the section stood 40 lbs. pressure to the square inch, and, in addition, I may say that these conduits have not leaked at all since their construction. This shows the wisdom of building the conduit all around in one piece, that is, in placing the concrete over the centers all at one time, instead of building a portion of it, and then

completing that portion later, after the lower portion had had an opportunity to set.

"The centers which I designed on this work were very simple and inexpensive, as will be gathered from the cost of the work, when I state that this conduit, which measured only 0.8 cu. yd. of concrete to the lineal foot of single conduit, cost only $6.14 per cu. yd., built with Atlas cement, including all labor and forms and material, and expanded metal. The forms were built in 16 ft. lengths, each 16 ft. length having five of the segmental ribbed centers such as are shown in Fig. 20, viz., one center at each end and three intermediate centers in the length of 16 ft. These segments were made by a mill in Newark and cost 90 cts. apiece, not includ-

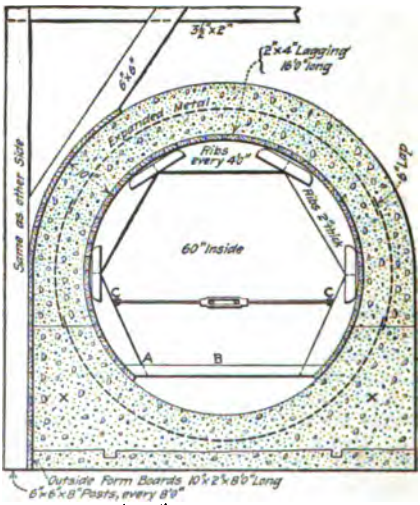


Fig. 20.—Centers for Concrete Conduit.

ing the bolts. We placed the lagging on these forms at the reservoir, and it was made of ordinary 2 x 4 material, surfaced on both sides, with the edges bevelled to the radius of the circle. These pieces of 2 x 4 were nailed with two 10d. nails to each segment. The segments were held together by four ½-in. bolts, which passed through the center, and 1½-in. wooden tie block. There was no bottom segment to the circle. This was left open, and the whole form held apart by a piece, B, of 3 x 2 spruce, with a bolt at each end bolted to the lower segment on each side.

"The outside forms consisted of four steel angles to each 16 ft. of the conduit, one on each end, and two, back to back, in the middle of each 16 ft. length. These angles were 2 x 3, with the 2-in.

side on the conduit, and the 3-in. side of the angle had small lugs bolted on it at intervals, to receive the 2 x 12 plank, which was slipped down on the outside of the conduit, as it was raised in height. The angles were held from kicking out at the bottom by stakes driven into the ground, and held together at the top by a ½-in. tie-rod.

"The conduit was 10 ins. thick, save at the bottom, where it was 12 ins. The reason for the 12 ins. at the bottom was that the forms had to have a firm foundation to rest on, in order to put all the weight required by the conduit on them in one day or at one time, without settling. We therefore excavated the conduit to grade the entire length, and deposited a 4-in. layer of concrete to level and grade over the entire length of the conduit line. This gave us a good, firm foundation, true and accurate to work from, and this is the secret of the good work which was done on these conduits. If you examine them, you will say that they are one of the neatest jobs of concrete in this line that has been built, especially with regard to the inside, which is true, level and absolutely smooth. [The author can confirm this statement.] When the conduit is filled with water, it falls off with absolutely no point where water stands in the conduit owing to its being out or the proper amount of concrete not being deposited.

"The centers were placed in their entirety on a new length of conduit to be built, resting upon four piles of brick, two at each end as shown. The first concrete was placed in the forms at the point marked X and the next concrete was dropped in through a trap door cut in the roof of the conduit form at the point marked Y. This material was dropped in to form the invert, and this portion was shaped by hand with trowels and screened to the exact radius of the conduit. The concrete was then placed continuously up the sides, and boards were dropped in the angles which I have mentioned, and which served as outside form holders till the limit was reached at the top, where it was impossible to get the concrete in under the planking and thoroughly tamped. At this point the top was formed by hand and with screeds.

"Each 16-ft. length of this concrete was made with opposite ends male and female respectively, that is, we had a small form which allowed the concrete to step down at one end to 3 ins. in thickness for 8 ins. back from the end of the section, and on the other end of the section it allowed it to step down to 3 ins. in thickness in exactly the opposite way, making a scarf joint. This was not done at every 16 ft. length, unless only 16 ft. were placed in one day. We usually placed 48 ft. a day at one end of the conduit with one gang of men. This was allowed to set 24 hours, and, whatever length of conduit was undertaken in a day, was absolutely completed, rain or shine, and the gang next day resumed operations at the other end of the conduit on another 48 ft. length. This was completed, no matter what the weather conditions were, and, towards the close. of this day the forms placed on the preceding day were being drawn and moved ahead.

"The method used in moving these forms ahead for another day's work is probably one of the secrets of the low cost of this work. and it is one which we have never seen employed before. The bolt at A, Fig. 20, was taken out, and the tie brace B thrown up. We had hooks at the points C. A turnbuckle was thrown in, catching these hooks, and given several sharp turns, causing the entire form to spring downward and inwards, which gave it just enough clearance to be carried forward, without doing any more striking of forms than pulling the bolt at A. This method of pulling the forms worked absolutely satisfactorily, and never gave any trouble, and we were able to move the forms very late in the day and get them all set for next day's work, giving all the concrete practically 24 hours' set, as we always started concreting in the morning at the furthest end of the form set up and at the greatest distance from the old concrete possible in the 48 ft. length, as the furthest form had, of course, to be moved first, it being impossible to pass one form through the other.,

"Six 16-ft. sections of these forms were built, and three were used each day on each end, as shown by the diagram MN, Fig. 20, which gives the day of the month for the completion of each of seven 48-ft. sections.

"A gang of men simply shifted on alternate days from end to end of the conduit, although several sections were in progress at one time; and of course, finally, when a junction was made between any division, say of 1,000 ft., to another 1,000 ft., one small form was left in at this junction inside of the conduit, and had to be taken down and taken out the entire length of the conduit.

"The centers for a 16-ft. length of this conduit cost complete for labor and material, $18.30, but they were used over and over again; and, after this conduit was completed, they were taken away for use at other points, so that the cost is hardly appreciable, and the only charge to centers that we made after the first cost of building the centers, was on account of moving them daily. Part of this conduit was built double (two 6-ft. conduits) and part single, the only difference being that, where the double conduit was built, two forms were placed side by side, and not so much was undertaken in one day.

"These conduits, when completed and dried out, rung exactly like a 60-in. cast-iron pipe, when any one walked through them or stamped on the bottom."

Mr. Woollard gives the following analysis of the cost per cubic yard of the concrete-steel conduit above described:

	Per cu. yd.
1.3 bbl. cement	$1.43
10 cu. ft. sand	0 35
25 cu. ft. stone	1.10
26 sq. ft. expanded metal, at 3 cts	0.78
Loading and hauling materials 2,000 ft. to the mixing board (team at $4.50)	0.50
Labor mixing, placing, and ramming	1.38
Labor moving forms	0.60
Total	$6.14

Wages were 17½ cts. per hr. for laborers and 50 cts. per hr. for foremen. The concrete was 1 : 2 : 5, a barrel being assumed to be 3.8 cu. ft. The concrete was mixed by hand on platforms alongside the conduit. The cost of placing and ramming was high, on account of the expanded metal, the small space in which to tamp, and to the screeding cost. When forms were moved they were scraped and brushed with soft soap before being used again.

From Mr. Morris R. Sherrard, Engr. and Supt. Dept. of Water, Newark, N. J., I have received the following data which differ slightly from those given by Mr. Woollard. The differences may be explained by the fact that the cost records were made at different times. Mr. Sherrerd states (Sept. 26, 1904) that each batch contains 4 cu. ft. of cement, 8 cu. ft. of sand, and 20 cu. ft. of stone, making 22 cu. ft. of concrete in place. One bag of cement is assumed to hold 1 cu, ft. He adds that a 10-hr. day's work for a gang is 63 lin. ft. of single 5-ft. conduit containing 47.4 cu. yds. of concrete and 1,260 sq. ft. of expanded metal. This is equivalent to ¾ cu. yd. of concrete per lin. ft. The total cost of material for one complete set of forms 64 ft. long was $160; and there were 7 of these sets required to keep two gangs of men busy, each gang building 63 lin. ft. of conduit a day. Since the total length of the conduit was 3,850 ft., the first cost of the material in the forms was 18 cts. per lin. ft.

Cost of Labor on 5-ft. Conduit:

	Per day.	Per cu. yd.
1 foreman on concrete	$ 3.35	$0.07
1 water boy	0.75	0.01
11 men mixing at $1.75	19.25	0.39
5 men mixing at $1.50	7.50	0.16
4 men loading stone at $1.40	5.60	0.12
4 men wheeling stone at $1.40	5.60	0.12
2 men loading sand at $1.40	2.80	0.06
2 men wheeling sand at $1.40	2.80	0.06
1 man placing concrete at $1.75	1.75	0.04
6 men placing concrete at $1.50	9.00	0.19
2 men supplying water at $1.50	3.00	0.06
1 man placing expanded metal at $2	2.00	0.04
1 man placing expanded metal at $1.50	1.50	0.03
Total labor on concrete	$64.90	$1.35

Cost of Labor Moving Forms:

	Per day.	Per cu. yd.
4 carpenters placing forms	$13.00	$0.27
2 helpers placing forms	4.00	0.08
1 carpenter putting up boards for outside forms	2.75	0.06
1 helper putting up boards for outside forms	2.25	0.05
2 helpers putting up boards for outside forms	3.50	0.07
1 team hauling lumber	4.50	0.09
1 helper hauling lumber	1.75	0.04
Total labor moving forms	$31.75	$0.66

It will be noted that it required two men to bend and place the 700 lbs., or 1,260 sq. ft., of expanded metal required for 63 lin. ft. of conduit per day, which is equivalent to 0.5 ct. per lb., or 0.3 ct. per sq. ft., for the labor of shaping, placing and fastening the metal.

Reference to Other Concrete Conduits.—In the section on Sewers

will be found more data on reinforced concrete conduits. See also Gillette and Hill's "Concrete Construction—Methods and Cost."

Cost of Brick Conduit.—A conduit of horseshoe shape, 7½ ft. in diameter, was built with a brick arch 8 ins. thick and a concrete invert lined with brick 4 ins. thick. The following relates to the brickwork. Work was done by contract, in 1884, in Massachusetts. Mr. Henry A. Carter gives the cost of 960 M of brickwork was as follows:

Labor:	
Foreman, 39 days, at $5.00	$ 195.00
Laborers, 320 days, at $1.25	400.00
Laborers, 1,752 days, at $1.50	2,628.00
Masons, 753 days, at $4.90	3,601.50
Carpenters, 4 days, at $2.50	10.00
Horse and car, 90 days, at $3.15	283.50
Miscellaneous labor	23.75
Materials:	
Brick, 960,000, at $8.40 per M	9,024.00
Cement, 315 bbls. Portland, at $3.20	1,008.00
Cement, 1,681 bbls. natural, at $1.26	2,118.06
Sand, 571 cu. yds., at $1.20	685.20
Plant:	
Boiler, 15 days, at $1.00	15.00
Pumps, 101 days, at $0.25	25.25
Cars and tools	79.00
Forms and centers	304.00
Coal, 12 tons, at $6.00	72.00
Office building	57.00
Total	$20,529.26
General expense, timekeeper, watchman, etc.	1,038.36
Grand total	$21,567.62

These 960 M of brick made 1,600 cu. yds. of masonry, or 570 bricks per cu. yd. About 5% were culled and rejected. It took 1.23 bbls. of cement per cu. yd. Masons each averaged 1,250 bricks per day, which was a poor average for men paid such high wages. The cost per cubic yard of this brick masonry was:

	Per cu. yd.
Masons laying, at 49 cts. per hr	$ 2.38
Laborers tending, including unloading, etc., 15 cts. per hr.	2.07
Brick, 570 at $8.40 per M	5.59
Sand, 0.35 cu. yd., at $1.20	0.42
Cement, 1.23 bbls.	1.55
Forms	0.19
General expense and miscellaneous	1.05
Total per cu. yd.	$13.25

The cost of 2,500 cu. yds. of concrete in the foundation and invert was as follows:

Labor:	Per cu. yd.
Foreman, at $2.75	$0.16
Laborers, 20 at $1.65	1.22
Carpenters, 2 at $2.25	0.15
Horse and car, at $3.15	0.15
Miscellaneous labor	0.01
Total labor	$1.69

Materials for concrete	$3.34
Lumber for forms	0.05
Cement shed	0.04
Tools, pumping, etc.	0.09
Grand total	$5.21

Weight of Iron or Steel Stand Pipes.—With iron or steel assumed to have a safe tensile stress of 12,500 lbs. per sq. in., assuming that single riveted joints have 66% of the strength of the solid sheet and that double riveted joints have 75%, each sheet to build 5 ft. Table XIII was calculated by Mr. A. H. Howland in 1886.

TABLE XIII.

Diam. standpipe, ft.	Gallons per ft. of depth.	Minimum thickness for top, ins.	Distance from top to carry minimum thickness, ft.	Distance from top to carry single rivets, ft.	Constant to add to minimum thickness for each 5 ft. below dist. given in 4th col., ins.
5	147.0	0.1455	105	65	0.0069
6	211.5	0.1494	90	55	0.0083
7	287.9	0.1455	75	50	0.0097
8	376.0	0.1554	70	45	0.0111
9	475.9	0.1500	60	40	0.0125
10	587.5	0.1525	55	35	0.0139
12	846.1	0.1670	50	30	0.0167
14	1,151.5	0.1940	50	30	0.0194
15	1,325.9	0.2080	50	30	0.0208
16	1,504.0	0.1989	45	25	0.0221
18	1,903.6	0.2192	40	25	0.0249
20	2,350.0	0.2218	40	25	0.0277
22	2,843.5	0.2440	40	25	0.0305
25	3,672.0	0.2425	35	20	0.0347
27½	4,442.7	0.2681	35	20	0.0383
30	5,304.0	0.2496	30	20	0,0418
33	6,398.2	0.2754	30	20	0.0459
35	7,197.0	0.2917	30	15	0.0486
40	9,400.0	0.3332	30	15	0.0555
45	11,897.0	0.3127	25	10	0.0625
50	14,688.0	0.3465	25	10	0.0693

From this table the details of any iron stand pipe can be determined and tabulated. Then from such a tabulation calculate the weight of the metal as follows: Figure the superficial area of the stand pipe of given diameter for a ring 5 ft. in height, multiply this by the weight of a square foot of metal of the thickness of each ring, add them all together and add the weight of the bottom, and then add 10% for laps and rivets.

Cost of a Standpipe, Quincy, Mass.—Mr. C. M. Saville gives the following relative to a 300,000 gal. steel standpipe built in 1900, at Quincy, Mass. The pipe is 30 ft. diam. and 64 ft. high. The lowest plates are 9/16 in. thick, and the top plates are ¼ in. thick. The bottom is of ⅜ in. plates. The bottom or floor plates and the first course were assembled and riveted, resting on rivet kegs directly

over their final location in the concrete foundation, and then lowered to place with hydraulic jacks.

In erecting, the contractor used inside and outside platforms swung from the top of the last plates set up, and for hoisting the plates he used a gin pole bolted to seams in this course. This pole was of such a length that a block at its top was 9 ft. above the top of the plate to which the pole was bolted. The hand winch was located on the ground. Riveting and calking were done with pneumatic machines, a 12 HP. Clayton air compressor (a larger compressor should have been used) and 25 HP. boiler being used. For calking a thick edged tool was required, as it made a better joint than a thin edged tool.

The side plates were first set up with bolts, and, when all were in place, the riveting was begun at the top and worked down, except in the case of the lowest two or three courses, when riveting kept pace with erection. The space between the bottom of the pipe and the concrete foundation was filled with neat cement grout, by means of a force pump, through grooves left for the purpose in the concrete foundation. During this process, 6 ft. of water were put into the standpipe to prevent its being lifted.

The actual cost (to the contractor) of the labor on the standpipe was nearly 0.9 ct. per lb., as follows:

	Per lb.
Assembling plates	$0.33
Riveting	0.42
Calking	0.10
Painting	0.40
Total	$0.89

The contractor's plant cost about $1,600. The gang employed was:

1 foreman at $3.50.
1 calker at $3.00.
1 riveter at $2.50.
1 engineman at $2.50.
2 heaters at $2.00.
3 helpers at $1.80.

The contract price for the standpipe was 3.8 cts. per lb. The actual cost to the contractor was 3.88 cts. per lb., as follows:

Materials:	
55 tons steel plates at $50	$2,750.00
1 ton L iron at $107	107.00
70 kegs rivets at $2.75	192.50
Bolts used in erection	10.00
Moving materials to and from shope and cars	250.00
Freight and materials	180.00
Total	$3,489.50
Labor:	
Assembling plates	$ 383.33
Riveting	488.38
Calking	111.95
Painting	47.36
Total	$1,031.02

Since the total weight of the standpipe was 116,450 lbs., the cost per pound was:

Materials	2.99 cts.
Labor	0.89 cts.
Total	3.88 cts.

The steel standpipe rests on a concrete foundation and is surrounded by a masonry tower. At contract prices the total cost was as follows:

Foundation:	
1,355 cu. yds. excavation	$ 514.90
284 cu. yds. concrete (48 ft. diam. × 5 ft. thick)	1,704.00
Grouting under standpipe	133.26
Total, foundation	$ 2,352.16
Standpipe	4,529.72
Masonry tower	24,790.00
Pipe connections	339.37
Grand total	$32,011.25

The masonry tower is 77 ft. high, 4¾ ft. thick at the base, 3½ ft. thick at a point 10 ft. above the base, 2 ft. thick at the top. The following are principal items in the tower:

925 cu. yds. rubble masonry (granite).

275 cu. yds. dimension stone (granite).

14 tons iron and steel work.

90 sq. yds. granolithic observation roof.

The so-called rubble was laid in courses with ¾-in. joints at the face. Between the tower and the standpipe the contractor erected a staging. Across the top of the standpipe were placed two pairs of 4 x 12-in. timbers, 30 ft. long and trussed with 1¼-in. rods. These timbers rested partly on the standpipe and partly on the staging. A platform was laid on these timbers and a guy derrick with a 20 ft. mast and a 30-ft. boom was mounted on the platform.

Cost of Steel Stand Pipe Encased in Brick.—Mr. Edward Flad gives the following data relative to a standpipe built in 1895 at St. Charles, Mo.

The tank is 25 ft. diam., 70 ft. high, and holds 250,000 gals. It is of steel plates (¼ to ⅝ in. thick) encased in brick, a space of 2 ft. being left between the brick and the steel. It rests on a foundation of natural cement concrete 5 ft. thick. The roof is of steel covered with slate. There are six horizontal circular girders riveted to the steel casing, to provide for wind pressure, acting like the stiffeners of a plate girder. The brick work is 9 ins. thick for the upper 30 ft. and 13 ins. thick for the lower 40 ft., and bears upon the circular girders just referred to. Eight brick pilasters (30 ft. high) were built for architectural effect, brick arches joining the tops of the pilasters. There is a steel cornice with a hand rail around the top. A light scaffold was built inside the tank, and cage swung on the outside, the plates being raised by a gin pole. A forge was placed on the cage and rivets were driven from the inside. After the iron work was in place, the brick casing was built from a scaffold.

The work was done by contract at the following prices:

Steel	$4,450
Brick casing	2,807
Foundation	678
Total	$7,935

Brick Casing Around Stand Pipe.—Mr. W. J. Laing gives the following data relative to a brick casing built in 1898 around an iron standpipe to prevent ice formation. The iron standpipe is 25 ft. diam. and 90 ft. high. It rests on a concrete pedestal 62 ft. high, 7 ft. of which is below ground level. This pedestal contains 1,200 cu. yds. concrete. The top of the standpipe is 145 ft. above ground level. The masonry casing around the standpipe is 162 ft. high, and contains 1,275 tons of broken stone, 13 cars of cement, 500,000 brick, and 5,000 lbs. of iron. It required 45,000 ft. B. M. of staging, and 16 men were three months building the casing.

Cost of a Steel Tank and Tower, Ames, Ia.—Mr. A. Marston gives the following relative to 162,000 gallon water tank mounted on a steel tower 110 ft. high, built at Ames, Ia., in 1897. The steel work is 24 ft. diam. x 40 ft. high (excluding the height of a hemispherical bottom). The curved roof is of galvanized iron on a steel frame work. The tank is supported by a tower composed of 8 Z-bar columns (12 in.) resting on 8 concrete pedestals. Each pedestal is 10 ft. square at the base, and 4 ft. square on top, capped with stone 18 ins. thick. The height of each pedestal is 7 ft. below the stone cap, and each contains nearly 19 cu. yds. of concrete. The contract price for the foundations was $1,150. The contract price for the steel tank and tower was $8,966, making a total of $10,116.

Cost of Steel Tank and Tower, Porterville, Calif.—Mr. Philip E. Harroun gives the following data relative to a 75,000 gal. tank on a tower, built in 1904 for the waterworks at Porterville, Calif.

The tank is of steel, 20 ft. diam. x 25 ft. high, plates being ¼ to 5/16 in., and has a hemi-spherical bottom. The tower has four legs 108 ft. long, resting on concrete pedestals. The foundation work was done by day labor at 20 cts. per hr. The tower and tank were erected by contract. The cost was:

157 cu. yds. excav. at 64¾ cts.	$ 101.74
52 cu. yds. backfill at 12¼ cts.	6.40
105 cu. yds. loaded and hauled ¾ miles at 20½	21.35
104.7 cu. yds. concrete (materials at $5.86, and labor at $1.88), at $7.74	810.53
65 cu. ft. granite capstones	231.55
78,532 lbs. steel, tower and tank, in place at 0.066	5,191.00
102 ft. screw pipe, 10 in. riser	269.23
Miscellaneous	19.51
Total	$6,650.81

Cost of Steel Tank and Tower, Fairhaven, Mass.—An elevated water tank was built at Fairhaven, Mass., in 1893. Its capacity is 383,000 gals. and its cost was $19,000. The steel tank is 35 ft. diam. x 50 ft. high, with a conical bottom, and is supported by 12 steel posts, 97 ft. high, surmounted by a girder 3 ft. high, total

100 ft. Each post rests on a masonry pedestal 9 × 9 ft. at the base 6 × 6 ft. at the top, 5½ ft. high, capped with a 4 × 4 ft. stone 1¼ ft. thick.

Cost of Steel Tank and Tower, Providence, R. I.—Mr. F. M. Bowman gives the following relative to a steel water tank and tower built in 1904 for East Providence, R. I. The cost was a little less than $100,000. The tower is 135 ft. high from base of column to base of tank; the steel tank is 50 ft. diam. × 70 ft. high, and holds 1,000,000 gals. The foundations are of concrete resting on solid rock.

Cost of Scraping and Painting a Stand Pipe. — Mr. Byron I. Cook says that it is practice to scrape and paint the interior of a stand pipe every two years. An old flat file, ground to a chisel edge, is used for scraping, and it costs less than 0.1 ct. (1 mill) per square yard for scraping. He prefers novices to regular painters. The cost of painting with two coats of Durable Metal Coating was:

Paint	$0.049 per sq. yd.
Labor	0.042 per sq. yd.
Total	$0.091 per sq. yd.

The outside of the pipe is not painted oftener than once in five years, with Dixon graphite paint.

Weight of Wooden Tank and Steel Tower.—A steel tower 80 ft. high and supporting a wooden water tank 28 ft. diam. × 22 ft. high (100,000 gals) weighed 100,000 lbs. This weight of steel included 25,000 lbs. of steel I beams (24 ins.) forming part of the platform on which the tank rested. Brick arches between these I beams formed the platform. The dead load was as follows:

	Lbs.
Tank	25,000
Water	830,000
Platform (brick)	70,000
Platform steel I beams	25,000
Tower	75,000
Total	1,025,000

Cost of a Wooden Water Tank, La Salle, Ill.*—The following figures of cost of constructing a wooden water tank are given by Mr. C. H. Nicolet, of La Salle, Ill. The tank was built to replace a tank which failed on March 29, 1905, because of the rusting and bursting of the iron bands or hoops. This old tank was 30 ft. in diameter and 24 ft. high, and was mounted on a circular stone tower 77 ft. high. It was built of Louisiana red gulf cypress, the staves and bottom being 3 ins. thick and the hoops 3/16 × 6 ins. and ¼ × 6 ins., with the usual spacing. The new tank was of the same dimensions and type, but with changes in details. The grade of the lumber was raised by limiting the amount of bright sap on any one edge to 1½ ins. This change increased the cost of the wood work about 11%. The most important change, however, was

*Engineering-Contracting, Sept. 26, 1906.

in the style of band used. Round rods were used. There were 29 hoops of 1⅛ in. diameter and six at the top 1 in. in diameter, all of mild steel. They were spaced 5 ins. apart on centers at the bottom and varying up to 21 ins. at the top. The hoops were made of three 30-ft. rods with a short filling piece, this being the limiting length obtainable from stock. The rods were bent to the proper curve before being placed. The joints were made by means of malleable iron lugs of the type commonly used in built-up stave pipe in the West. The cost of the tank as described was as follows:

Materials:		
Tank complete at mill (wood work only) "Tank grade"		$ 698.00
Added for raising grade of lumber		76.00
Freight		39.00
		$ 813.00
Rods, 1⅛ in. round	10,046 lbs.	
Rods, 1 in. round	1,734 lbs.	
	11,780 lbs.	
11,780 lbs., at $1.85 Chicago		217.95
Lugs, 116—1⅛-in. at 43½c	$41.76	
Lugs, 24—1-in. at 36c	8.64	
		50.40
Total materials		$1,081.35
Labor:		
Machinists and helpers—threading and bending rods, grinding lugs, etc., 214 hours		$ 45.00
Carpenters and helpers, removing debris of old tank and erecting new tank and roof; also painting, 907 hours		200.00
Laborers—mainly removing debris of old tank		10.00
Total labor		$ 255.00
Grand total		$1,336.35

It will be noticed that the labor of putting on the roof is included above, but not the material. This consisted of a flat cover made of 1¾ in. tongued and grooved plank resting on 2 × 12 in. joists tops flush with top of tank, supported on two trucks with cups, and two 6 × 6 in. posts, each set on tank bottom.

Cost of Concrete Standpipes.*—Mr. George H. Snell, Mr. Frank A. Barbour, and Mr. Leonard C. Wason give the following data relative to a reinforced concrete standpipe built in 1904 at Attleborough, Mass. The standpipe is 50 ft. diam. x 100 ft. high, and holds 1,500,000 gals. The experience, gained with a former standpipe of iron indicated that a steel pipe would have a life of only 20 years, because the water contained carbon dioxide (CO_2). Two tons of rust had been removed annually from a wrought-iron standpipe 30 ft. in diam. x 125 ft. high. The bid on a steel standpipe, 50 ft. x 100 ft., was $37,135. The bid of the Aberthaw Construction Co. on the reinforced concrete standpipe and gate house was $34,000, which was accepted.

The concrete wall is 18 ins. thick at the bottom and 8 ins. thick at the top. The bottom is of concrete 1 ft. thick, and the concrete foundation, 18 ins. thick, rests on hardpan 7 ft. below the ground

**Engineering-Contracting*, Dec. 26, 1906.

level. The concrete foundation is of 1 : 3 : 6 concrete. The walls are of 1 : 2 : 4 concrete, reinforced with round steel rods (0.40 carbon). Rods of milder steel would have been better, for it was difficult to bend them so that they would hold their shape, on account of their springiness. Twisted steel rods could not be bent in true planes and had to be abandoned. The rods were pulled through a tire bender around a curved form by a steam engine. The rods were in 56½-ft. lengths, and were spliced by overlapping 30 ins., using three Crosby guy-rope clips without which it would have been very difficult to secure a satisfactory splice. It was at first attempted to support these hoops, or rings, with vertical rods of twisted steel, but, due to lack of rigidity of these rods, 4-in. channels were substituted, spaced 11 ft. apart. It would have been better had the channels been closer. Holes were punched through the flanges of the channels at proper intervals, and ½-in. pins inserted to support the hoops or rings as in Fig. 21. Up to a height of 60 ft. there were two rings of 1½-in. bars spaced 3¾ to 8 ins. vertically. There were 2½ ins. of concrete outside of the outer ring, and 4 ins. between the two rings. From 60 to 81 ft. there was but one ring,

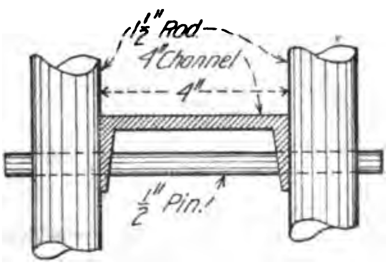


Fig. 21.

spaced as shown in Fig. 22. Above 81 ft. the diameter was reduced to 1⅛ ins.

The labor of bending and placing the steel actually cost $9 per ton, or 0.45 ct. per lb. The Crosby clips cost 37 cts. each.

The cost of the 1 : 2 : 4 concrete in the walls was as follows:

	Per cu. yd.
Cement	$ 4.80
Sand and stone	3.90
Mixing concrete	0.40
Placing concrete	2.20
Forms, labor and lumber	2.65
480 lbs. steel, assumed at 2 cts.	9.60
Bending and placing 480 lbs., at 0.45	2.16
4 Crosby clips, at 0.37	1.48
Total	$27.19

There are 770 cu. yds. in the walls, which, at $27.19, gives an actual cost of $20,936. This does not include the cost of plastering and waterproofing.

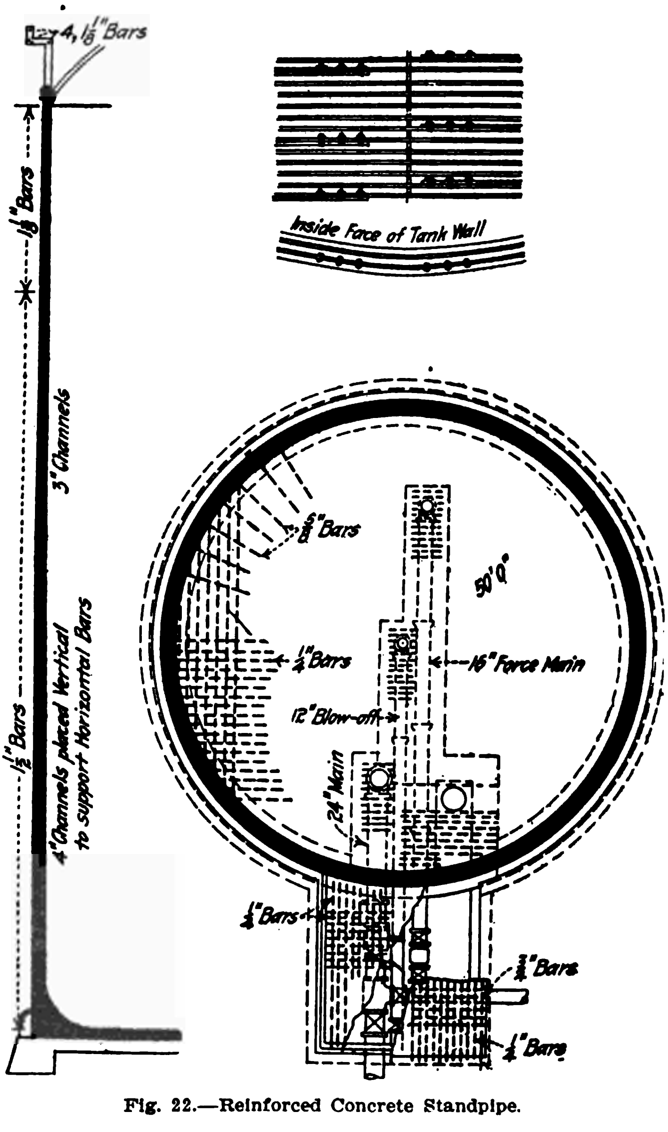


Fig. 22.—Reinforced Concrete Standpipe.

There are nearly 90 cu. yds. in the floor, which are included in the 770 cu. yds. above given. There are about 230 cu. yds. of 1 : 3 : 6 concrete in the foundation.

The standpipe has an ornamental concrete cornice and a dome-shaped roof of Guastavino tile.

A timber tower 60 ft. high was erected inside the standpipe and a derrick with a 40-ft. boom was mounted on the tower, the derrick being operated by an engine on the ground. When the standpipe had reached a height of 60 ft., the height of the tower was increased to 110 ft. and the derrick raised. The cost of this tower and of raising the derrick was $1,700, which is equivalent to $2.20 per cu. yd. This is charged against the item of forms and of placing concrete.

The plant included a Sturtevant roll jaw crusher, bucket elevator and rotary screen, and a Smith mixer.

The floor and a section of wall 2½ ft. high were molded in one operation, after which the wall was built up in sections 7½ ft. high. The reinforcing was first built up to a height of 7½ ft. and then the forms were placed. The forms were made in sections 11 ft. long. The lagging of the outside forms was boards nailed vertically to wooden ribs. The lagging of the inside forms was boards placed, one at a time, horizontally, as the wall was built up, so that the concrete was always easily accessible. The sections of forms were locked together by iron clamps. Two sets of forms were used, so that one set was left in place while the other was being raised and made ready to receive the concrete. The batter of the outside of the tank increased the difficulty of the work, for they had to be adjusted from time to time to provide for the decreasing circumference. It is questionable whether the cost of this adjusting did not exceed the saving of concrete effected by the use of a batter.

Fig. 23 shows the timber tower and the standpipe partly built.

Fig. 22 shows the design of the standpipe.

Since the wall was built in sections 7½ ft. high, great care was taken to secure a perfect joint between the sections. At the top of each concrete section a groove was formed by a 2 x 3-in. strip of beveled wood. When this was removed, the top surface was well scrubbed with water and coated with neat cement. This joint proved very effective. The operation of placing steel and raising forms for a new section took three days, so that the concrete surface was quite hard when concreting was resumed.

The concrete was dumped on platforms on the tower and shoveled into the forms. Care was taken not to make the concrete so wet that spading and ramming would drive the stone to the bottom and leave porous spots. The mixture must not be more wet than will enable the mortar to support the broken stone. Atlas Portland cement was used throughout.

After the wall had reached a height of 20 ft., the tank was filled

with water, and it was kept filled, as the work progressed, to the elevation of the bottom of the lowest set of forms. Considerable leakage developed at first, but this gradually grew insignificant, although the waterproof coat had not yet been placed. At no time was more than 1 to 2 per cent of the exterior surface wet by leakage. During the winter some of the concrete scaled off near the bottom on the outside, apparently due to cavities outside the steel reinforcement, probably caused by a slight moving of the forms

Fig. 23.—Erecting Concrete Standpipe.

when the concrete was being placed. Repairs were made by digging around the outside rows of steel reinforcement, putting on iron clips (¾ x ¼ in.) of iron bolted through, and then forcing cement into the cavities around the clips by throwing it a distance of 4 ft. against the wall. Expanded metal was then fastened to the clips, and covered with cement plaster, and then more expanded metal was put on over this and plastered.

The inside of the tank was plastered after roughening the surface of the concrete with a pick. The plastering seemed to have

little effect in absolutely stopping the leakage. The lower 25 ft. were subsequently given 5 more coats of plaster without entirely stopping leakage. Finally the surface was treated by the Sylvester process, as follows:

Thoroughly dissolve ¾ lb. pure Castile olive oil soap to each gallon of water. Thoroughly dissolve 1 lb. of pure alum in 8 gals. of water. Thoroughly clean the wall and dry it. Apply the soap solution boiling hot, with a flat brush, taking care not to form a froth. Wait 24 hours so that the solution will become dry and hard upon the walls, then apply the alum solution in the same way, at a temperature of 60 to 70° F. Wait 24 hours, and repeat with alternate coats of soap and alum.

In 1870 this process was used successfully to waterproof brick walls on the Croton reservoir, 4 coats of each solution being sufficient; 1 lb. of soap covered 37 sq. ft., and 1 lb. of alum covered 95 sq. ft.

After applying four coats of each solution to the concrete standpipe, up to a height of 35 ft., water was admitted to a height of 100 ft., and only four leaks developed. Then four more coats were applied to this 35-ft. section, and above that only four coats were used.

It was found, by tests at the Watertown Arsenal, that three Crosby clips developed the full tensile strength of the 1½-in. reinforcing rods.

The design of this tank and further details are given in "Concrete Construction" by Gillette and Hill.

Materials in a Reinforced Concrete Stand Pipe.—Mr. J. L. H. Barr gives the following relative to an 81-ft. standpipe of reinforced concrete built in 1903 at Milford, Ohio.

The outside diameter is 15½ ft. The shell is 9 ins. thick for the lower 30 ft., 7 ins. thick for the next 25 ft., and 5 ins. thick for the remaining 26 ft. The concrete foundation is octagonal, 20 ft. diameter of inscribed circle, and 6 ft. thick. The shell is made of 1:3 mortar (no stone) reinforced with 1 x 1 x ⅛-in. T bars. The vertical bars are 18 ins. c. to c.; the horizontal bars are spaced 6 to the foot for the lower 30 ft., 5 to the foot for the next 25 ft., and 4 to the foot for the remaining 26 ft.

The forms were 3-ft. staves (1⅛ x 3 ins.) nailed to circular ribs (4 x 4 in.), the topmast rib extending 1 in. above the tops of the staves so as to form a rabbit to receive the next form. Three sets of forms were used, each 3 ft. high. Each set consisted of an inner and an outer form, each divided into 8 segments for ease of handling. This standpipe required:

68 cu. yds. gravel containing 40% sand (for base).
90 cu. yds. sand (for shell).
270 bbls. cement.
25,000 lbs. steel.

There would appear to be insufficient steel in the horizontal rings, since the tensile stress at the bottom is nearly 22,000 lbs. per sq. in.

The amount of gravel for the base or foundation appears to be approximately correct, since it would be about 70 cu. yds. of concrete; but the amount of sand appears to be overestimated, as the shell would contain but 60 cu. yds. The base inside the shell was covered with 1:3 mortar 6 ins. deep, which would require about 3 cu. yds.

It is stated that the contract price for this standpipe was $200 less than the lowest bid for a steel standpipe.

Cost of 12-in. Well, Portersville, Calif.—Mr. Philip E. Harroun gives the following cost of 12-in. well, 216 ft. deep, driven in 1904 at Portersville, Cal. The material penetrated was clay. The contract price for drilling the well and driving the casing was $2 per lin. ft. The well had a double casing, the inner casing being No. 14 gage, and the outer being No. 16 gage, in 2-ft. lengths. The casing cost $1 per ft. thus making the total cost $3 per ft. Various incidentals added $50 to the cost of the well.

Relative Cost of Waterworks and of Filters.—When it is generally known that it costs about $100 to produce a million gallons of water in the average city, and less than $10 to purify it by filtration—including plant interest and depreciation in both cases—there is certain to be far less hesitancy about incurring the expense of providing filter plants. Somehow the impression prevails that pumping water and delivering it through pipes is very cheap, and that filtering is exceedingly expensive, whereas it costs ten times as much to supply water as it does to filter it under ordinary conditions. The expensive system of piping that underlies the streets of a city costs about $350 per capita of population, whereas a slow sand filter plant capable of supplying 100 gals. per capita per day costs only $3.50 per capita, and a mechanical filter plant costs less than $2.70 per capita. In other words, by an expenditure of about 1% more than the first cost of a piping and pumping system for a city of less than 100,000 population a filter plant can be added to the existing water supply system.

It is true that the cost of operating a filter plant is not correspondingly small, but it is a relatively small item nevertheless. As will be seen from the data subsequently given, the principal cost of operating a sand filter is the scraping and cleaning the sand, and replacing it on the filter bed. Year by year, improved methods have been developed for washing and handling the sand, and the end of this development is by no means reached yet.

Cost of Filter and Filtering, Ashland, Wis.—Mr. William Wheeler gives the following relative to a slow sand filter built in 1895 at Ashland, Wis. This was the first sand filter plant in America to be covered with masonry. The 3 filter beds have an area of ⅛ acre. They are so located on the lake shore that it was necessary to

build a pile bulkhead around three sides of the filter beds. The walls are of concrete and brick, 3 ft. thick at the bottom and 2 ft. at the top. The beds are roofed with groined elliptical brick arches (15¾ ft. span), resting on brick pillars, and backed with concrete. Two courses of brick laid flat form the arch rings (5 ins. thick). The floor is of concrete only 3 ins. thick. It is below the lake level, which necessitated building a cofferdam during construction. The sand beds are 4 ft. thick resting on 9 ins. of gravel. The work of construction was entirely by day labor. The cost was as follows:

470 lin. ft. cofferdam (not with earth filling)	$ 1,720
Handling water	493
6,943 cu. yds. earth excavation	3,238
340,400 bricks, laid in walls	6,237
45,000 bricks, laid in piers	827
349,550 bricks, laid in roof arches	6,755
Centers for roof arches (labor and materials)	1,157
37 manholes	724
House over effluent chamber and sump well	627
1,000 cu. yds. concrete	5,977
Vitrified collecting pipes, laid	116
Cast-iron collecting pipes, laid	639
Cast-iron supplying pipes, laid	725
Pipe, pipe connections, pump, etc.	729
880 cu. yds. gravel in filter beds	1,949
3,385 cu. yds. sand in filter beds	4,201
Sundries	2,268
Engineering and superintendence	1,800
Total	$40,178

This is equivalent to about $80,000 per acre, but, had it not been for the difficult conditions and winter work, the cost would have been $5,000 less, or $70,000 per acre, including pump well, sump well, effluent chamber, piping and housing. A further reduction of 10 to 15 per cent in cost could be effected where building stone and suitable sand and gravel were near at hand.

This plant filtered 1,100,000 gals. per day, or at the rate of 2,200,000 gals. per acre per day. It required 10 scrapings of sand per year, removing 610 cu. yds. of sand, which was equivalent to 1.52 cu. yds. of sand scraped per million gallons. The cost of this scraping was 62 cts. per million gallons, or 40 cts. per cu. yd. of sand, the cost of scraping a bed of one-sixth acre being as follows:

3 men scraping, ½ day, at $1.50	$2.25
2 men wheeling in filter, ½ day, at $1.50	1.50
1 man tending bucket at bottom, ½ day, at $1.50	0.75
2 men load and dump at bottom, ½ day, at $1.50	1.50
1 man wheeling away at top	0.75
1 single team to hoist bucket	2.50
Tools and sundries	0.50
Total for 1/6 acre	8.50

There were 21 cu. yds. of sand (plus the mud) removed at each cleaning of a bed, making the cost 40 cts. per cu. yd. The dirty sand was not washed, but new, clean sand was delivered by contract and placed for $1 per cu. yd. Hence the cost of scraping sand and of replacing with new sand cost $1.40 per cu. yd. of sand scraped,

or $2.13 per million gallons. Adding 13 cts. to this for superintendence, etc., the total cost of filtering was $2.26 per million gals. At 5 per cent interest on the first cost of the plant, the capital charges are $5.05 per million gallons, making a total of $7.31 per million gallons.

Cost of Filter, Berwyn, Pa.—Mr. J. W. Ledoux gives the following data relative to a small (½ acre) sand filter plant built in 1898 at Berwyn, Pa. It has a nominal filtering capacity of 1,500,000 gals. per day. The filters are built in 3 compartments (not roofed) each having 7,500 sq. ft. effective filtering area, or about 85 ft. square. A vertical section through the filter beds shows 30 ins. of sand, 6 ins. of gravel, 3 ins. of concrete floor and 8 ins. of puddle. The main drains are 12-in. vit. sewer pipe; the laterals are 4-in. tile, spaced 6 ft. apart, set in depressions in the concrete. The side walls are of rubble, outside of which is the embankment. The cost, including a $2,000 gate house and accessories, was as follows:

6,772 cu. yds. excavation, at $0.241	$ 1,630.80
528.3 cu. yds. stone masonry, filter basin, at $5.541	2,927.31
2.4 cu. yds. brick masonry, filter basin, at $9.16	21.98
304.5 cu. yds. concrete, filter basin, at $6.153	1,873.43
2,432 sq. yds. plastering and forming gutters, at $0.243	591.60
3,200 lin. ft. 4-in. tile drain, in place, at $0.065	207.20
246 lin. ft. 12-in. collecting drain, at $0.654	160.80
286 lin. ft. 12-in. clean-out drain, at $1.198	342.64
281 lin. ft. 12-in. cast-iron inlet and outlet pipes, at $1.571	441.57
200 lin. ft. 14-in. cast-iron filter discharge, at $2.192	438.36
542 cu. yds. puddle, at $0.709	384.63
655.55 tons gravel in filter bottom, at $2.115	1,386.62
2,696.83 tons sand in filter bottom, at $1.639	4,420.10
97.2 cu. yds. stone masonry, gate house, at $7.234	703.07
10.75 cu. yds. brick masonry, gate house, at $7.38	79.33
125.3 cu. yds. excavation and back fill, gate house, at $0.985	123.43
Roofing (slate), woodwork and painting, gate house	210.81
9,584 lbs. flange pipe (12-in.), gaskets, etc., at $0.031	296.26
Registering and weir apparatus	272.45
Valves (6 to 12-in.), with boxes and band wheels	254.69
Superintendence and engineering	729.00
Incidentals	1,000.00
Total	$18,535.59

Since the filter bed has a total area of 22,500 sq. ft., the cost was about 82 cts. per sq. ft. (including cost of the gate house), or $35,700 per acre. This cost is equivalent to $12,000 per million gallons of daily capacity. The "superintendence and engineering" was 4 per cent of the total cost.

Cost of Filter, Nyack, N. Y.—Mr. G. N. Houston gives the following relative to a slow sand filter plant built in 1899 at Nyack, N. Y. The filter beds are not roofed. There are two beds 74 x 116 ft. each, having a combined filtering area of 0.38 acre. The maximum consumption of water at Nyack was 630,000 gals. per day, which would require a filtering capacity of 3,300,000 gals. per acre per day, if only one bed were used, but, in practice, both beds are used except when one is being cleaned. The raw water is drawn by gravity from a nearby creek. The filter is located in a swamp.

adjacent to the creek, which made its construction expensive. In order to deliver the creek water by gravity to the filter, it was necessary to excavate for the filter beds to a depth of 10 ft. The material was a wet tenacious clay whose banks would crack and slip, so that it was necessary to support the side walls on piles. The clay was spaded out in chunks that were lifted by hand into wagons. Temporary plank roads had to be laid. Sheet piles were driven all around the filter beds and left in place. Bents of bearing piles were driven underneath the retaining walls, capped and floored with plank. On this pile foundation, which cost $3 per lin. ft. of wall, was built a small concreted retaining wall for a height of 3 ft. 8 ins., the top of this wall being about the same elevation as the top of the sand in the filter bed. The earth slope above the retaining wall was paved with 8 ins. of concrete and vitrified brick for a length of about 6 ft. measured up the 1½ to 1 slope. The division wall was also supported on a pile foundation, and was of concrete up to the level of the surface of the filter sand, and above that it was of vitrified brick 2 ft. thick. The work was done by contract at the following cost to the village:

Excavation (10½ ft. deep and about 7,000 cu. yds.)	$ 5,270
Grading and soiling	1,500
Sheet piles, 66,000 ft. B. M., at $50	3,300
Bearing piles, 352, at $4.42	1,558
Hemlock caps and floor	838
Yellow pine caps and floor	465
Concrete floor, 10½ ins. thick ($1.50 per sq. yd.)	2,738
Concrete walls, 430 cu. yds., at $4.40	1,892
Concrete slope paving	484
Brick slope paving, 13.45 cu. yds., at $8.40	113
Blue-stone curb	250
Vitrified pipe drains (about 1,400 lin. ft. of 6-in. and 230 ft. of 15-in.)	347
Gravel (12 ins.) and sand (36 ins.), 2,570 cu. yds., at $2.15	5,524
House over regulating chamber	150
Pipe laying	58
Miscellaneous	250
Total	$24,737
Engineering ($3,644) and inspection ($713)	4,357
Total, 0.38 acres, at $76,553	$29,094

This is an unusually high cost, due to the conditions above given, and to the fact that the work was dragged along, which made the expense of engineering and inspection high. The price of filter gravel and sand was high, as it was brought by scow from Long Island.

The above costs include a clear water well 25 ft. in diameter, with side walls 12 ft. high, and a dome-shaped roof of concrete.

The plank "floor" includes not only the floor laid on the bearing piles, but a 1-in. hemlock floor laid over the entire bottom of the filter bed on which the concrete was placed.

Cost of Filter and Filtering, Superior, Wis.—Mr. R. D. Chase gives the following data relative to a sand filter and aeration plant built in 1899 for Superior, Wis., to remove the iron from water from

driven wells. There are 3 filter beds, each 67 x 108 ft., and with these in operation there is 0.5 acre filtering area, with a capacity of 5,000,000 gals. daily, or 10,000,000 gals. per acre per day. This rapid rate of filtration is justified because there is no mud or bacteria.

The pure water reservoir is 39 x 108 ft. The floor, sides and roof are of concrete, the piers supporting the roof being of brick 20 ins. square and 12 ft. high. The floor is of inverted groined arches, and the roof is of groined arches, 12 ft. span and 2½ ft. rise, 6 ins. thick at the crown. The roof is covered with 2 ft. of earth.

The excavation was red clay, expensive to handle, the actual cost being 55 cts. per cu. yd.

Each filter bed has 20 manholes, 3 ft. diam., 3 ft. high, of concrete 8 ins. thick, with double covers of steel plates.

The outside walls of the filter beds are 2½ ft. thick at the top, and 3¾ ft. thick at the base.

The construction of the pure water reservoir is similar to that of the filters, and the reservoir has a capacity of 300,000 gals.

The main underdrains are 20-in. tile, laid in concrete beneath the floor. The lateral drains are of 6-in. tile, 12 ft. apart. The gravel was dredged from the lake. Under normal conditions 4 ft. of water is kept on top of the sand.

The outside dimensions of the 3 filter beds and the pure water reservoir, all under one roof, are 116 ft. x 255 ft.

The construction was done by day labor, working under a contractor who was paid a percentage for supervision. Laborers were inefficient, yet received $2 a day. The actual cost was as follows:

Filters and pure water reservoirs:	
14,000 cu. yds. excavation, at $0.55+	$ 7,630
2,000 cu. yds. backfill (roof, etc.), at $0.30+	600
3,000 cu. yds. concrete, at $7.85+	23,500
Arch centering	1,910
120 cu. yds. brickwork, at $10.00	1,200
Tile pipe	860
600 cu. yds. filter gravel, in place, at $4.95	2,970
1,600 cu. yds. filter gravel, in place, at $3.04	4,864
800 cu. yds. filter gravel, in place, at $0.97	776
Aerator	470
Miscellaneous charges	2,350
Engineering and percentage to contractor	9,204
Total	$56,334
Land	6,280
Iron pipe, pump, pump house, etc.	26,870
Grand total	$89,484

Since the total area was 116 x 255 = 29,580 sq. ft. (0.68 acre), the excavation must have averaged about 13 ft. deep.

It will be noted that the filter gravel was exceedingly expensive, as was most of the filter sand. The sand for one bed, however, was obtained without dredging and at a cost of only 97 cts. per cu. yd.

The cost of cleaning a filter bed is as follows:

5 men scraping, 3 hrs., at 20 cts.	$ 3.00
1 team hoisting, 2 hrs., at 40 cts.	0.80
5 men hoisting, 2 hrs., at 20 cts.	2.00
5 men smoothing, 2 hrs., at 20 cts.	2.00
Total, labor, 10 cu. yds., at $0.78	$ 7.80
10 cu. yds. new sand to be replaced, at $1	10.00
Grand total, 10 cu. yds., at $1.78	$17.80

About 12,000,000 gals. are filtered through each bed (0.25 acre) between scrapings, so that 0.83 cu. yd. of sand is scraped per million gallons, and the cost per million gallons is:

Labor scraping and removing sand	$0.65
Clean sand replaced	0.83
Total	$1.48

The dirty sand is hoisted in tugs by a team, a tripod with a block and tackle being placed temporarily over each manhole during hoisting.

Cost of Filter and Filtering, Washington, D. C.—Mr. Allen Hazen and Mr. E. D. Hardy give the following data:

This is a slow sand filtration plant treating 70,000,000 gals. daily, and its cost was $3,356,300 (including $619,900 for land), or $47,950 per million gallons daily capacity. Assuming interest and depreciation at 5 per cent per annum, the capital charge is $7 per million gallons, for an average of 67,000,000 gals. per day, and the operating expense is about $2 per million gallons, making a total of $9 per million gallons filtered.

The summarized cost of the plant is as follows:

Pumping station, etc.	$ 183,600
29 filters, 29 acres, at $75,758	2,197,000
Filtered water reservoir	150,000
Lower gate house and pipe line	24,300
Land	619,900
Engineering and clerical	181,500
Total, 29 acres, at $115,735	$3,356,300
Total, exclusive of land	2,736,400

The detail cost was as follows:

Pumping Station:

Intake, with gates and building	$ 11,500
Venturi meters, 72-in. and 54-in.	5,000
Electric lighting, engines, etc.	7,000
Four 200-hp. boilers, in place	14,800
Four Roney stokers	4,100
Two Green fuel economizers, in place	5,100
Three 36-in. centrifugal pumps and engines	42,000
Two sand-washer pumps	8,100
Piping, valves, etc.	13,100
Coal, oil and running tests	3,500
Traveling crane	1,600
Chimney (with foundation)	5,800
Building (with foundation and well)	51,000
Total, pumping station	$183,600

Twenty-nine Filters:

862,700 cu. yds. excavation, at 30 cts.	$ 258,800
299,500 cu. yds. filling, at 30 cts.	89,900
Sodding and seeding slopes	7,300
Roads and drains outside of filters	16,200
Concrete tunnel under First St.	3,100
Concrete (including cement):	
36,563 cu. yds., floors, at $6.75	246,800
19,038 cu. yds., walls, at $7.35	139,900
6,964 cu. yds., piers, at $8.25	57,500
34,920 cu. yds., roof (vaulted), at $8.75	305,500
Ramps leading to tops of filters	6,800
Court paving	43,000
7,900 ft. Central underdrains, at $1.65	13,000
Interior drainage system, 29 filters, at $500	14,500
Drainage of roofs, 29 filters, at $266	7,700
Materials placed in concrete, 29 filters, at $200	5,800
157,725 cu. yds. filter sand, at $2.65	418,000
36,500 cu. yds. filter gravel, at $2.75	100,400
Cast-iron pipe and specials	117,000
Steel rising main and concrete backing	76,800
Pressure pipe system	2,600
Sand-washer pipe system	24,000
Sand washers, 19 washers and 8 ejectors	4,800
Elevated sand bins, 29, capacity 250 cu. yds. each	60,800
Exterior drainage system	25,300
Venturi meters and indicating apparatus	11,400
Sluice gates and gate valves	19,900
Regulator houses	27,300
Office and laboratory	19,700
Shelter house for workmen	4,800
Water and gas lines to buildings	11,200
Electric lighting for courts and filters	41,900
Cleaning up and miscellaneous	11,600
Total, filters, 29 acres, at $75,758	$2,197,000

Filtered Water Reservoir:

83,500 cu. yds. excavation, at 30 cts.	$ 25,100
18,000 cu. yds. filling, at 30 cts.	5,400
15,290 cu. yds. concrete, at $7.60	116,000
Gate house superstructure	3,500
Total, reservoir	$150,000

Lower Gate House:

Pipe lines	$ 6,000
Gate house	18,300
Total, gate house	$ 24,300

Engineering and Clerical:

General plans	$ 36,000
Surveying	32,000
Field office force	21,000
Main office force	67,000
Watchmen	4,500
Temporary office	1,000
Total engineering	$181,500

The engineering was 6.65 per cent of the total cost of construction, which is a high percentage on so large a contract.

This Washington filter plant is similar to the Albany plant, but

it cost 65 per cent more per acre, due principally to the higher contract prices, especially the price for filter sand which cost $2.65 per cu. yd. at Washington as compared with $1 per cu. yd. at Albany. It was anticipated by the Washington contractors that the cost of producing filter sand of specified cleanliness would be far greater than it really was.

Cost of Filtering at Washington, Albany and Philadelphia.—Mr. J. A. Vogleson gave the following table of cost of cleaning filter sand per cubic yard:

	Washington (1906).	Albany (1899-1901).	Philadelphia Belmont (1905).	Philadelphia Upper Roxboro' (1905).
Scraping	$0.05	$0.13	$0.21	$0.18
Removing	0.16	0.25	0.23	0.22
Washing	0.05	0.30	0.30	0.09
Replacing	0.13	0.25	0.25	0.30
Total, per cu. yd.	$0.39	$0.93	$0.80	$0.79
Rate of wages, per 8 hrs.	$1.50	$1.50	$1.75	$1.75
Cost, per million gals.	$0.60	$1.66	$1.25	$0.63

The low cost of cleaning Washington filters is due to the method used. After scraping the sand into piles, it is shoveled into an ejector and carried through a hose to a 4-in. pipe, and thence to the sand washers, and thence through pipes to the sand bins, from which it is drawn off into carts and dumped through the roof of the filter into a rotatable chute which discharges it where desired.

The cost of 30 cts. per cu. yd. for "replacing" the sand at Upper Roxboro, Philadelphia, is the contract price, the work being done with wheelbarrows. Before the replacing was done by contract, it cost the city 52 cts. per cu. yd. by day labor, thus furnishing another one of the numberless examples of the greater efficiency of contract labor.

Cost of Filter and Filtering, Albany, N. Y.—Mr. Allen Hazen describes the slow sand filter plant built at Albany, N. Y., in 1898-1899, giving the following data:

The plant has a capacity of 14,700,000 gals. per day, and its first cost was $500,000, including the pumping plant. There are 8 filter beds of 0.7 acre filtering area each (121 x 258-ft. bed), and with one bed out of use for the purpose of being cleaned the yield of the 7 beds is 14,700,000 gals. daily, or 3,000,000 gals. per acre of bed in active service. The water is pumped from the Hudson River into a 5-acre (14,600,000-gal.) sedimentation basin (380 x 600 ft.), 9 ft. deep, the 2 centrifugal pumps having a total capacity of 24,000,000 gals. per 24 hrs. against a lift of 24 ft. Half of the pumping plant is capable of supplying the ordinary consumption. The clean water reservoir holds only 600,000 gals., being very small because the old distributing reservoirs are used to store the filtered water after it is pumped from the clear water reservoir.

The cost of this plant, in round numbers, was as follows:

Sedimentation basin	$ 60,000
Clear water reservoir	9,000
Filters (at $45,600 per acre)	255,000
Pumping station	50,000
Conduit from filter to pumping station	87,000
Engineering, laboratory equipment, etc.	31,000
Total	$492,000
Land	8,000
Grand total	$500,000

This is equivalent to nearly $35,000 per million gallons of daily capacity. Strictly speaking, the conduit from the filter to the pumping station should not be included, and, if its cost ($87,000 is deducted, we have a cost of about $30,000) per million gallons of daily capacity.

The plant was built by contract, and the following is a more detailed statement of the cost to the city:

Filters, Sedimentation Basin and Pure Water Reservoir:

Preliminary draining	$ 1,956.71
70,672 cu. yds. excavation, at $0.308	21,761.64
16,040 cu. yds. rolled embankment, at $0.52	8,340.80
22,851 cu. yds. silt and loam filling, at $0.15	3,427.65
23,439 cu. yds. general filling, road, at $0.18	4,219.02
12,550 cu. yds. puddle, at $0.715	8,973.25
1,775 cu. yds. gravel lining, at $0.85	1,508.75
2,257 sq. yds. split stone lining, at $0.82	1,850.74
11,737 cu. yds. concrete in floors, at $2.31	27,112.47
7,792 cu. yds. concrete in roof vaulting, at $3.85	29,999.20
3,147 cu. yds. all other concrete, at $2.13	6,703.11
4,382 cu. yds. brick work, at $8.125	35,603.75
31,715 bbls. Portland cement, at $1.935	61,368.53
7,281 cu. yds. filter gravel, at $1.05	7,645.05
36,488 cu. yds. filter sand, at $1.00	36,488.00
Cast-iron pipes and specials	21,841.25
Gates and valves	6,714.23
672 filter manhole covers, at $4.40	2,956.80
8 sand-run fixtures, at $407.50	3,260.00
8 regulator houses, at $862.24	6,897.92
1 office and laboratory	4,881.00
Vitrified brick paving	2,158.00
Iron fence about court	1,704.00
Extra work and minor items	9,692.01
Total	$324,217.20

The excavation averaged 4 ft. deep. The 6-in. vitrified drains were placed 14 ft. apart. The main vitrified drains (12 to 30 ins.) were placed beneath the concrete floor, being bedded in concrete.

The price for concrete does not include the Portland cement, which is a separate item. The concrete was mixed 1 : 3 : 5, a barrel being 3.8 cu. ft., and required 1.26 bbls. cement per cu. yd.

The actual cost of the concrete is given on p. 748.

The floor of the filter was of concrete, built in the form of inverted grained arches to distribute the pressure over the subsoil. The roof was of concrete, groined arches (6 ins. thick at crown, span 12 ft., rise 2½ ft.), supported by brick piers 21 ins. square by

9¼ ft. high. The outside walls were of concrete lined with 8 ins. of brick, and the division walls were of brick.

The gravel and sand were dredged from the river with a dipper dredge having a daily capacity of 500 cu. yds., but the average output was 300 cu. yds. The sand was pumped into a stock pile.

According to Mr. W. B. Fuller the cost of roofing the filter was about 30 per cent of the total cost of the filters, or $13,700 per acre, or 31½ cts. per sq. ft. This includes not only the brick piers and earth covering over the roof, but the extra thickness of the floor necessary to carry the added load.

The cost of one section of concrete floor, brick piers and concrete roof, 13 ft. 8 ins. square (187 sq. ft.), at contract prices was:

4.85 cu. yds. floor, at $4.75	$23.04
1.24 cu. yds. brick, at $9.67	11.99
5.40 cu. yds. roof, at $6.30	34.02
Total, 187 sq. ft., at 36.9 cts	$69.05

This gives an average thickness of 7 ins. of concrete in the floor. Deducting the cost of the floor, we have left 25 cts. per sq. ft. as the cost of the piers and the roof. This does not include the cost of the 2-ft. earth fill over the concrete roof, which added about 10 cts. per sq. ft., the price of the silt fill being only 15 cts. per cu. yd. This roof was entirely effective in preventing freezing.

A reinforced concrete roof was considered, but was not adopted because the city water board objected to anything "experimental."

The cost of operating the filter plant from September 5 to December 25, 1899 (118 days), was $1.67 per million gallons, for 12,500,000 gals. per day.

The following was the ordinary force of men:

	Per day.
10 laborers, at $1.50 for 8 hrs	$15.00
1 foreman	2.75
1 watchman	1.50
Total labor	$19.25
1 chemist	3.00
Total	$22.25

The cost of pumping was $2.52 per million gals., the following being the daily cost:

3 engineers, at $2.48	$ 7.44
3 firemen, at $1.98	5.94
3 tons coal, at $2.72	8.16
1 laborer, at $1.50	1.50
9 gals. engine oil, at $0.09	0.81
2 gals. cylinder oil, at $0.11	0.22
5 gals. kerosene, at $0.10	0.50
5 lbs. waste, at $0.07	0.35
Steam packing, sheet rubber, soap, soda, maps, cloths, etc	6.58
Total	$31.50

Neither of the above costs for filtering or pumping include interest, depreciation and repairs.

The amount of sand scraped and cleaned was 0.7 cu. yds. per million gallons. The labor cost was as follows per cubic yard:

1.44 hrs. of man scraping, at 18¾ cts.	$0.270
2.63 hrs. of man wheeling, at 18¾ cts.	0.493
2.44 hrs. of man washing, at 18¾ cts.	0.458
1.92 hrs. of man refilling, at 18¾ cts.	0.360
8.43 Total	$1.581

This is equivalent to $1.19 per million gallons, exclusive of foreman's time, cost of wash water, etc. The volume of water for washing the sand was about 13 times the volume of the sand. About ⅝ in. of sand (not including the mud) was scraped off at each scraping, requiring 76 hrs. of a man's time to scrape an acre. The sand was wheeled out in barrows averaging only 1 cu. ft. per barrow load, the average haul being 300 ft. from point of loading to the sand washer. The filters yielded 66,600,000,000 gals. per acre between scrapings.

The sand is washed in sand washers of the ejector type, there being 5 ejectors in each sand washer through which the dirty sand must pass.

Mr. Geo. I. Bailey gives the following relative to the cost of filtering through slow sand filters at Albany, N. Y., and at Lawrence, Mass., both being for the year 1899:

	Albany (3,817 million gals.)	Lawrence (1,170 million gals.)
Ice cutting and snow	....	$1.91
Scraping sand	$0.25	....
Scraping and replacing sand	....	3.18
Wheeling out	0.50	....
Washing sand	0.59	1.25
Conveying sand	....	1.31
Refilling	0.39	....
Incidentals	0.20	0.43
Repairing elevator and tools	....	0.11
Cleaning basin	0.06	....
Total	$1.99	$8.19

Interest and depreciation are not included, nor is pumping. The Lawrence plant makes a miserable showing. Scraping and replacing includes scraping the beds, wheeling to a roadway, and carrying the sand back from the washing machine and spreading on the beds. Conveying sand means loading and transporting it (470 ft.) from the roadway to the washing machine. Wages were 25 cts. per hr.

The Albany plant was operated 319 days (July 26, 1899, to July 1, 1900), giving nearly 12,000,000 gals. per day. Labor was paid 18¾ cts. per hr. The daily average was 2,630,000 gals. per acre. The average run was 65,500,000 gals. per acre between cleanings. There were 5,200 cu. yds. of sand and mud wheeled out (yielding 3,687 cu. yds. washed sand), and 3,500 cu. yds. of washed sand wheeled back. Each barrow wheeled out contained 2 cu. ft. (71,702 wheelbarrow loads), and each barrow wheeled back contained 1.6 cu. ft. (59,590 barrow loads). Hence there were practically 1 cu.

yd. of washed sand per million gallons, and the above costs per million gallons at Albany are also practically the costs per cubic yard of sand handled.

The following is the cost for the 319 days at Albany (add 15 per cent for a full year's cost of wages, etc., but also add 15 per cent to the amount filtered):

Filter:	
Labor..	$5,107.62
Superintendence	1,392.58
Tools and supplies	377.75
Half the cost of miscellanies	304.75
Wash water for sand at 1 ct. per 100 cu. ft.	209.06
Total, at $1.94 per million gals.	$7,391.76
(Add 5 cts. per million gals. for cleaning sedimentation basin.)	
Pumping:	
Engineers and firemen	$4,258.65
Laborers	387.00
Coal and supplies	3,497.84
Oil, packing, etc.	799.06
Half cost of miscellanies	304.75
Total, at $2.42 per million gals.	$9,247.30
Laboratory:	
Chemist	$ 999.96
Laborer	69.38
Laboratory supplies	245.15
Total, at $0.34 per million gals.	$1,314.49
Total cost per million gals., incl. pumping, but not incl. capital charges	$ 4.75

Mr. John H. Gregory gives the following relative to the Albany filter plant operation, during 1899 to 1900, covering a period of 500 days.

Scraping required 0.69 hrs. labor per cu. yd., or 13 cts. per cu. yd. of sand. There were 1.23 cu. yds. of sand scraped (to a depth of 0.66 in.) per million gallons, so that the cost of scraping was 16 cts. per million gallons. This covers only the labor cost of scraping the dirty sand into piles.

Wheeling out the sand includes shoveling it into barrows, wheeling it 250 ft., and raking and screeding the filter bed. Its cost was 1.29 hrs. labor, or 25 cts., per cu. yd.; and, since there were 1.23 cu. yds. per million gals., the cost of wheeling was 30 cts. per million gallons. The raking and screeding of the bed consumed about 25 per cent of the time of the men engaged in shoveling and wheeling, one man raking and screeding 11,000 sq. ft. per day.

Washing the sand includes handling the dirty sand from the storage piles to the sand washer, attendance on the washer, and removing the washed sand to a storage pile. The ejector type of washer was used. The cost was 1.57 hrs. labor, or 30 cts. per cu. yd. of sand, or 27 cts. per million gallons filtered.

Refilling filter beds with clean sand includes removal from storage piles to filter bed, loosening the top layer of sand about 6 ins. deep, and leveling the new sand. Its cost was 1.31 hrs. labor, or 25 cts. per cu. yd., or 22 cts. per million gallons.

Mr. George I. Bailey gives the cost of filtering at Albany, for the year 1900:

Labor	$ 6,131.63
Incidentals	574.92
Lost time	451.32
Superintendence	2,161.43
Supplies	552.25
Supplies, miscel.	604.84
Wash water	226.92
Total	$10,703.31

	Hours.	Total.	Per million gals.
Scraping	5,481	$ 1,532.70	$0.24
Wheeling out	10,238	2,863.20	0.45
Refilling	7,437	2,081.66	0.32
Incidentals	3,009	841.25	0.13
Lost time	2,365	662.10	0.10
Washing	8,923	2,722.40	0.42
Total	37,453	$10,703.31	$1.66

The equiv. cost per cu. yd. of sand was:

Wheeling out	$0.36
Refilling	0.37
Washing	0.48

Wages are $1.50 per 8-hr. day.

The round trip is 500 ft. from the filter bed to the storage piles.

In scraping, a long-handled shovel with a blade 12 ins. wide enables a man to scrape more than 100 sq. yds. per hr.

It was found that one run plank 14 ins. wide gives better service than two 10 to 12-in. planks, and it takes half as long to place the single plank.

The wheels of the ordinary wheelbarrows were readjusted so as not to put so much weight on the arms of the men in ascending grades.

The men shovel the dirty sand from the storage pile into a movable hopper, whence the sand is carried by a current of water through a pipe to the washer, thus saving wheeling it to the washer. Men wheel the sand away from the washer.

The average run is 26 days between scrapings, or 70,000,000 gals. per acre, 12½ parts of water to 1 part of sand are used in washing, costing 4 cts. per cu. yd. of sand.

Cost of Groined Arches and Forms on the Albany Filter Plant.—The following data are given by Mr. Allen Hazen and Mr. William B. Fuller. The concrete was mixed in 5-ft. cubical mixers in batches of 1.6 cu. yds. at the rate of 200 cu. yds. per mixer day. One barrel of cement, 380 lbs. net, assumed to be 3.8 cu. ft., was mixed with three volumes of sand weighing 90 lbs. per cu. ft., and five volumes of gravel weighing 100 lbs. per cu. ft. and having 40% voids. On the average 1.26 bbls. of cement were required per cu. yd. The conveying plant consisted of two trestles (each 900 ft. long) 730 ft. apart, supporting four cableways. The cables were attached to carriages, which ran on I-beams on the top of the trestles. Rope drives were used to shift the cableways along the trestle. Three-ton loads were handled in each skip. The installa-

tion of this plant was slow, and its carrying capacity was less than expected. It was found best to deliver the skips of concrete to the cableway on small railway track, although the original plan had been to move the cableways horizontally along the trestle at the same time that the skip was traveling.

The cost of mixing and placing the concrete was as follows;

	Per cu yd.
Measuring, mixing and loading	$0.20
Transporting by rail and cables	0.12
Laying and tamping floors and walls, including setting forms	0.22
Total	$0.54

The cost of laying and tamping the concrete on the vaulting was 14 cts. per cu. yd. The vaulting is a groined arch 6 ins. thick at the crown and 2½ ft. thick at the piers.

The lumber of the centering for the vaulting was spruce for the ribs and posts, and 1-in. hemlock for the lagging. The centering was all cut by machinery, the ribs put together to a template, and the lagging sawed to proper bevels and lengths. The centers were made so that they could be taken down in sections and used again. The cost of centering was as follows:

Labor on centers covering 62,560 sq. ft.:	
Foreman, 435 hrs. at 35 cts.	$ 152.25
Carpenters, 4,873 hrs. at 22½ cts.	1,096.42
Laborers, 3,447 hrs. at 15 cts.	517.05
Painters, 577 hrs. at 15 cts.	86.55
Teaming, 324 hrs. at 40 cts.	121.60
Total labor building centers 313 M at $6.37.	$1,973.87
Materials for centers covering 62,560 sq. ft.:	
313,000 ft. B. M. lumber, at $18.20	$5,700.00
3,700 lbs. nails, at 3 cts.	111.00
8 bbls. tar, at $3	24.00
Total	$5,835.00

These centers covered two filters, each having an area of 121⅓ x 258 ft. There were six more filters of the same size, for which the same centers were used. The cost of taking down, moving and putting up these centers (313 M) three times was as follows:

Foreman, 2,359 hrs. at 35 cts.	$ 825.65
Carpenters, 12,766 hrs. at 22½ cts.	2,872.35
Laborers, 24,062 hrs. at 15 cts.	3,609.30
Team, 430 hrs. at 40 cts.	172.00
3,000 ft. B. M. lumber, at $20	60.00
3,000 lbs. nails, at 3 cts.	90.00
Total cost moving centers to cover 196,660 sq. ft.	$7,629.30

The cost of moving the centers each time was $8.10 per M, showing that they were practically rebuilt; for the first building of the centers, as above shown, cost only $6.37 per M. In other words, the centers were not designed so as to be moved in sections as they should have been. Although the centers were used four times in all, the lumber was in fit condition for further use. The cost of the labor and lumber for the building and moving of these cen-

ters for the 8 filter beds, having a total area of 259,220 sq. ft., was $15,438, or 6 cts. per sq. ft.

Cost of Filter and Filtering, Lawrence, Mass. — Mr. Morris Knowles and Mr. Charles G. Hyde give the following data relative to the slow sand filter plant built in 1892 at Lawrence, Mass. The plant was built by day labor and cost $80,000. It consists of 25 filter beds, having a total filtering area of 2.36 acres, so that the cost of the plant was $34,000 per acre. The raw water enters the filter from the Merrimac River by gravity. The filters are not roofed, although, as will be seen later on, the cost of roofing is abundantly justified by the cost of ice removal.

Between the years 1897 and 1900, inclusive, the beds were scraped 15 times yearly. The average depth of sand removed at each scraping was ¾ in., making a total of about 3,500 cu. yds. of sand yearly over the entire surface. About 1,200,000,000 gals. per year, or 3,500,000 gals. per day, were filtered during this period, which is equivalent to only 1,400,000 gals. per acre per day, or about half what a modern slow sand filter delivers. Nearly 3 cu. yds. of sand were scraped per million gallons filtered, which is far in excess of amount ordinarily scraped.

The cost per million gallons for the year 1900, which was typical, was as follows:

Scraping sand	$1.75
Sanding	1.02
Conveying sand	1.16
Washing sand	1.25
Removing snow and ice	1.92
General	0.60
Total	$7.70
Add (5% of $80,000) ÷ 2,100 mill. gals.	1.90
Total	$9.60

The capital charge of $1.90 per million gallons is none too high, and takes into consideration no charge for "special repairs."

In this year of 1900, 3,000 cu. yds. of sand were scraped off in filtering 2,100 million gals., or 2.48 cu. yds. per million gallons, hence the above figures of cost per million gallons if divided by 2.48 will give the cost per cubic yard of sand handled, or:

Scraping	$0.70
Conveying	0.46
Washing	0.50
Sanding	0.40
Total per cu. yd.	$2.06

Scraping includes not only scraping off the dirty sand and throwing it into small piles, but loading and wheeling (75 to 150 ft.) in barrows to a temporary dump just inside the filter bed. It also includes smoothing the beds after cleaning.

Conveying including loading the dirty sand from the temporary dumps into carts and hauling and depositing in a permanent dump near the washer.

Washing includes screening dirty sand, washing and transporting to the stock pile of clean sand.

Sanding includes cost of loading and wheeling in the clean washed sand and spreading it.

Wages of laborers were $2 per 9-hr. day.

The sand washer consists of 4 hoppers. The sand drops to the bottom of each hopper, where it strikes a horizontal jet of water and is carried into a pipe that leads up into the next hopper. The water required is about 10 times the volume of sand, or 270 cu. ft. of water per cu. yd. of sand. Four men attend to screening and wheeling to the washer, washing and taking the sand away in dump cars; they can thus wash 21 cu. yds. of sand daily at a cost of $8 for labor, or 38 cts. per cu. yd., but delays due to shifting of the washer, etc., and cost of repairs make a total cost of 50 cts. per cu. yd.

Mr. M. F. Collins, superintendent of the plant, states that the average depth to which the sand is scraped is greater for an unroofed filter than for one that is roofed, due to the fact that when there is any snow on the filter bed the men usually scrape too deep with their shovels, and when the bed is frozen slightly they necessarily must take off an excess of sand to get below the frost. Possibly this accounts largely for the abnormally great amount of sand scraped at Lawrence; possibly the method of scraping is itself not what it should be.

Mr. John H. Gregory gives the following additional information for 1900. The cost per million gals. was as follows, labor being separated from materials, supplies, etc., and from superintendence:

Scraping (labor)	$1.50
Conveying (labor)	1.02
Washing (labor)	0.94
Sanding (labor)	0.90
Removal of snow and ice (labor)	1.56
General (labor)	0.38
Superintendence	0.91
Materials, supplies, etc.	0.52
Total	$7.73

He states that 1.94 cu. yds. were scraped per million gals. filtered, requiring 3.53 hrs. labor per cu. yd., or 77 cts. per cu. yd., wages being $2 for 9 hrs., average thickness scraped being ½ in.

He states that 3,000 cu. yds. were washed in 1900, at a cost of 38 cts. per cu. yd. for labor, requiring 1.72 hrs. labor per cu. yd.

He states that 3,400 cu. yds. of clean sand were put on, at a cost of 32 cts. per cu. yd. for labor, or 1.47 hrs. labor per cu. yd.

From the year 1896 to 1900, inclusive, the average cost of snow and ice removal was $2.20 per million gals., or nearly $1,100 per acre per annum. Since an acre could be roofed for about $15,000, it is evident that it would be much cheaper to pay interest on a roof. However, the Lawrence filters show about half the ordinary output of water per acre attained by well designed beds, so that if their filtering capacity per acre were doubled, the cost of snow and ice removal would be $1.10 per million gals.

Cost of Filter and Filtering, Vernon, N. Y.—A slow sand filter was built at Mt. Vernon, N. Y., in 1894, at a cost of about $25,000. The area of the filter beds is 1.1 acres, and about 1,900,000 gals

were filtered per day. The average cost of filtering during the years 1897 to 1900 was as follows per million gals.:

Scraping and removing sand	$1.63
Washing sand	0.58
Replacing sand	0.58
Removing ice	0.42
Miscellaneous	0.10
Total	$3.31
6% interest on filter plant ($1,500 ÷ 680 million gals.)	2.20
Grand total	$5.51

An average of 1,300 cu. yds. of sand was cleaned per year (there being about 15 scrapings a year), or nearly 2 cu. yds., cleaned per million gals. Hence by taking half of the above figures we have the cost of cleaning the sand per cubic yard, or a total of nearly $1.40 per cu. yd. The scraping is done with shovels, the sand being removed in wheelbarrows. The sand washers are like those used at Albany (hoppers with ejectors). It is estimated that 12,000 gals. of water are used to wash each cubic yard of sand.

Cost of Filtering, Poughkeepsie.— Mr. Charles E. Fowler gives the following relative to the operation of the Poughkeepsie filter in 1900.

The sand is not scraped into heaps, but is shoveled direct into barrows. The back of a rake is used to level the surface after scraping. It takes 23 men 2 days of 8 hrs. each to scrape 1⅛ acres, wages $1.50 a day, cost $49 per acre. This includes wheeling to the corners of the filter bed, throwing up to top of coping and trimming back the pile.

The sand is stored and washed in October and replaced all at one time (16 days). Washing costs 32 cts. per cu. yd., and replacing costs 26 cts. per cu. yd., for a total of 910 cu. yds.

The total number of scrapings per year is not stated, but if there were 15 the cost was $1.20 per cu. yd. for scraping, added to $0.58 for washing and replacing; total $1.78 per cu. yd. (Mr. Gregory gives the cost of scraping at $1.30 per million gals. in 1900.)

The cost of ice removal varied from $146 to $613 a year, and averaged $364 for four years prior to 1901, or $273 per year per acre. To remove a 16-in. layer of ice in 1901 cost $408 per acre of filtering area, wages being $1.50 per 8-hr. day. The ice was sawed in parallel lines in one direction and broken by chisels in the other direction. The cakes were floated to a run at the side of the basin and pulled up by men with pikes. The water level was about 1 ft. below the top of the coping. The cakes were then pushed on nearly horizontal runs to the place of deposit, which costs about half of the total cost of ice removal. The cost of ice removal was 94 cts. per million gals. filtered that year, and there was only this one removal.

Cost of Washing Filter Sand, Poughkeepsie, N. Y.—Mr. Charles E. Fowler gives the following relative to sand washing at the Poughkeepsie filters in 1897. With two hoppers, and an upward water jet in each, the cost of washing the sand was 24 cts. per cu.

yd., laborers being paid 18 cts. per hr. The sand was delivered through a pipe to a tank 130 ft. away, and, after the remaining silt had flowed over the top of this tank, the sand was drawn off through a valve. Fifty cu. yds. of sand were washed per 10-hr. day, requiring 18 cu. ft. of water to each cu. ft. of sand, the water costing 3 cts. per cu. yd. of sand.

Cost Ice Removal From Filters.—Mr. John H. Gregory gives the following costs of snow and ice removal from filter beds per million gallons:

Lawrence (average 1896 to 1900)	$2.20
Poughkeepsie (average 1898 to 1900)	0.48
Mt. Vernon (average 1897 to 1900)	0.28

Estimated Cost of Filters and Filtering, Cincinnati, O. — Mr. George W. Fuller made the following comparative estimates of the cost of slow sand filtering and mechanical filtering for the city of Cincinnati, O., in 1899. A year's work with an experimental plant, of 100,000 gals. daily capacity, preceded the estimate. The plant designed for Cincinnati is to have a daily capacity of 80,000,000 gals. The estimated cost includes no allowance for cost of land, and covers only the expense from the time the water is discharged into the subsiding basins until it leaves the clear water reservoir by gravity. The clear water reservoir is to hold 20,000,000 gals. The settling reservoirs are to hold 320,000,000 (48 hrs. subsidence or 96 hrs. capacity). The rate is to be 3,000,000 gals. per acre per day in the slow sand filter, and 125,000,000 in the mechanical filter. The following are the estimated first costs per million gallons daily capacity:

	——Filter Plant.——	
	Slow sand.	Mechanical.
Reservoirs	$16,000	$16,000
Pipe connections	500	500
Filter beds, chemical devices, piping, laboratory, etc.	16,667	7,500
Clear water reservoir	1,250	1,250
Coagulating and supplementary subsiding reservoir (20,000,000 gals.)	....	1,500
Total cost per million daily gals.	$34,417	$26,750
Interest and sinking fund (5% per year) per million gals.	$4.72	$3.67

The cost of operation of the slow sand filter plant is estimated thus:

	Pear year.
1 superintendent	$ 4,000
1 assistant superintendent	2,400
2 analysts, at $1,500	3,000
3 assistants, clerks and janitor, at $600	1,800
1 night watchman	720
3 reservoir attendants, at $720	2,160
3 filter attendants, at $720	2,160
1 storekeeper	720
5 chemical attendants for 6 mos. each year, at $360	1,800
Extra labor	1,500
Total, 29,200 million gals., at $0.72	$20,860

The cost per million gallons is estimated thus:

Salaries (as above given)	$ 0.72
Ice removal, etc.	0.30
Scraping 20 times a year, 325 man-hrs. per scraping, at 20 cts. per hr.	1.19
Washing sand, 1.75 cu. yds., at 40 cts.	0.70
Replacing sand, 1.75 cu. yds., at 20 cts.	0.35
Sulphate of alumina, 0.95 gr. per gal., at 1.4 cts. per lb.	1.90
Repairs, 0.5% cost per yr.	0.47
Total operating expense	$ 5.63
Capital charges (as above)	4.72
Grand total	$10.35

The estimated cost of salaries for a mechanical filter plant of the same capacity is as follows:

15 attendants for filters and chemical devices, at $720	$10,800
3 firemen, at $720	2,160
1 mechanic	1,440
3 engineers, at $1,440	4,320
1 superintendent	4,000
1 assistant superintendent	2,400
2 analysts	3,000
3 assistants, clerks, etc.	1,800
1 night watchman	720
3 reservoir attendants	2,160
Extra labor	1,500
Total, 29,200 million gals., at $1.17	$34,300

The estimated cost of operating the mechanical filter plant is as follows per million gallons:

Salaries (as above)	$1.17
Wash water, 5% of filtered water, at $15 per million gals.	0.75
Coal for power and light	0.15
Sulphate of alumina, 1.6 grs. per gal., at 1.4 cts. per lb.	3.20
Repairs and replacements, machinery and chemical devices, 10% per yr. on $2,500	0.69
Other repairs, 0.5% of first cost per yr.	0.33
Total operating expense	$6.29
Capital charges (as above)	3.67
Grand total	$9.96

For the turbid water of the Ohio River at Cincinnati, Mr. Fuller recommended a mechanical filter plant.

Cost of Filtering and Ice Removal, Reading, Pa.*—The water supply of Reading, Pa., is obtained by gravity systems and by pumping. Two of the gravity supplies—the Antietam supply and the Egelman supply—are filtered. Mr. Emil L. Neubling, Superintendent and Engineer of Waterworks, gives data for the fiscal year ending April 6, 1908.

Antietam Filters.—The Antietam supply is obtained from a drainage area of 5.44 square miles. The storage reservoir capacity is 101,000,000 gallons. During the year this supply was treated with copper sulphate in order to remove the organism anabaena and to lighten the work of scraping at the Antietam filters. Two treat-

**Engineering-Contracting,* Oct. 28, 1908.

ments were given and the effect upon the operation of the filters was to reduce the total number of scrapings from 62 in the previous year to 48 during the past year.

The Antietam filters consist of three open sand beds, 108 x 144 ft. each, the capacity of each bed being 1,750,000 gallons per day. The filters were put into service on May 11, 1905. The total cost of operation and maintenance was $3,909.46 or $474.76 less than the previous year. Owing to the decreased efficiency of labor the cost of refilling the beds was 42 per cent higher per cubic yard than during the previous year. The cost of washing sand, however, was very materially reduced on account of placing the filter keeper in charge of the washing, thereby saving the services of an engineer. The cost of washing sand was reduced 11 cts. per cu. yd.

During February and March, 1908, 835 cu. yds. of ice was removed from the filter. The mean thickness of the ice was 4.35 ins., and the greatest average thickness was 5.3 ins. in February, when three beds were cleared. In March one bed was cleared, the average thickness of ice being 1.5 ins. The cost of removing the ice was as follows:

	Total.	Per cu. yd.
Labor, 238 hours	$51.69	$0.062
Superintendence	6.80	.007
Supplies	.90	.001
Total	$59.39	$0.070

It will be noticed common labor was paid about 21 cts. per hour.

The cost of scraping and wheeling out sand was as follows, 1,818 cu. yds. being removed:

	Total.	Per cu. yd.
Labor, 3,589½ hours	$711.77	$0.391
Superintendence	38.82	.021
Supplies	70.29	.039
Sulphate treatment	42.77	.024
Total	$863.65	$0.475

The cost of washing sand, 1,831 cu. yds. being washed, was as follows:

	Total.	Per cu. yd.
Labor, 1,539½ hours	$282.38	$0.154
Superintendence	30.43	.017
Supplies and repairs	794.49	.433
Total	$1,107.30	$0.604

The cost of refilling the beds was as follows, 1,921 cu. yds. of sand being used for refilling:

	Total.	Per cu. yd.
Labor, 4,838 hours	$917.95	$0.478
Superintendence	37.03	.020
Supplies	18.36	.010
Total	$973.34	$0.508

The total number of gallons of water filtered during the year was 1,182,557,923. The average quantity of water filtered between scrapings was 73,909,870 gallons or at the rate of 69,626,123 gallons per acre. The average quantity of water filtered per day was

3,231,033 gallons, or at the rate of 3,043,765 gallons per day per acre. The cost of filtering water per million gallons was as follows:

	Total.	Per million gals.
Removing ice	$ 59.39	$0.050
Scraping and wheeling out sand	863.65	.730
Washing sand	1,107.30	.936
Refilling beds	973.34	.823
Care of grounds	513.86	.434
Analyses	37.38	.030
Watching	150.09	.130
Operation and general maintenance	204.45	.180
Total	$3,909.46	$3.313

The cost of filtering water per million gallons, excluding analyses and care of grounds was $2.84.

Engelman Filters.—The Engelman supply has a drainage area of 0.6 square miles and a storage reservoir capacity of 6,900,000 gallons. The Engelman filter consists of two open sand beds, 40 x 55 ft. each; the capacity of each bed is 250,000 gals. per day. The filters were put into service on July 11, 1903.

On account of not washing sand and refilling beds during the year, the cost of operation was considerably less than for the previous year. The unit cost of scraping and wheeling out sand was 3 cts. per cubic yard more than for the previous year, and the cost of ice removal 2 cts. per cubic yard less.

A total of 147 cu. yds. of ice was removed from these filters, the mean thickness of the ice being 3.6 ins. The greatest thickness was 5.2 ins. in February, 1908. The cost of removing ice was 10 cts. per cubic yard, the work requiring 67 hours labor at a total cost of $11.05.

The cost of scraping and wheeling out sand was as follows:

	Total.
Labor, 450½ hours	$82.82
Superintendence	1.70
Total	$84.52

A total of 122 cu. yds. of sand was removed, the cost per cubic yard being $0.69.

The total number of gallons of water filtered during the year was 79,784,796. The average quantity of water filtered between scrapings was 4,693,234 gallons, or at the rate of 48,675,541 gallons per acre. The average quantity of water filtered per day was 217,992 gallons, or at the rate of 2,260,888 gallons per acre per day.

The cost of filtering the water per million gallons was as follows:

	Total.	Per million gals.
Removing ice	$ 14.05	$0.177
Scraping and wheeling out sand	82.82	1.038
Operation and general maintenance	109.56	1.373
Analyses	31.10	.391
Care of grounds	45.25	.567
Total	$284.48	$3.546

The cost of filtering water per million gallons, exclusive of cost of analyses and care of grounds was $2.61.

Cost of Filtering, Brooklyn, N. Y.—Mr. I. M. de Varona gives the following data relative to 4 filter plants in Brooklyn, 2 mechanical and 2 slow sand filters. The mechanical filter plant at Baiseleys is of the gravity type and has a normal capacity of 5,000,000 gals. per day. It has circular wooden tanks; air is used to agitate the sand during washing.

The mechanical filter plant at Springfield is similar to that at Baiseleys, but its normal capacity is only 3,000,000 gals. per day, For the 12 mos. of 1905 the cost of operating these plants was as follows:

	Baiseleys.	Springfield.
Inspection	$ 484.80	$ 462.79
Operation	4,714.08	3,182.91
Laboratory	443.68	409.23
Repairs	507.78	232.53
Interest and sinking fund	3,218.64	2,366.28
Total	$9,363.98	$6,653.74
Million gals. filtered	1,435.5	694.6
Cost per million gals.	$6.53	$9.58

The Forest Stream slow sand filter plant has two sand beds having a daily capacity of 6,000,000 gals., the area of the bottom of the beds being 2 acres. The beds have no covering and have no impervious bottom, nor side walls. Collecting pipes are laid below the ground water level, so there is practically no loss of water by this form of construction. The bed is underlaid by gravel, and the 6-in. underdrains are 12¼ ft., c. to c.

The Hempstead slow sand filter plant is similar to the Forest Stream plant, but the two beds have an area of only 0.9 acre and a daily capacity of 3,000,000 gals.

The cost of operating these plants during 1905 was as follows:

	Forest Stream.	Hempstead.
Inspection	$ 348.91	$ 214.76
Laboratory	335.12	419.26
Labor and materials	710.00	239.47
Interest only	1,058.40	330.00
Total	$2,452.43	$1,203.49
Million gals. filtered	1,075.3	416.8
Cost per million gals.	$2.28	$2.89

At Hempstead a new method of cleaning the beds was used, which consists in washing the beds instead of scraping them. The cost of this cleaning by washing was 40 cts. per million gals. instead of $1 by scraping. The beds are divided into channels 20 ft. wide, by means of boards set vertically, extending 8 ins. above the surface and 6 ins. below the bottom of the sand. The boards are laid to within 15 ft. of the ends of the beds, and boards can be placed across the ends of the channel ways so as to cause a flow of water through any desired channel way. When the bed is ready to be cleaned it is drained so that only 4 or 5 ins. of water are left on the bed, and waste pipe gate is opened; then a gate on the pipe

between the two beds is opened to allow the raw water in the adjoining bed to flow into the bed to be cleaned. The velocity of the water is regulated so that it will not quite carry the sand. Men with rakes stir up the surface of the bed, so that the dirt is carried away in suspension. The men work from the head of the bed toward the outlet. When one channel is cleaned, stop planks are placed across its end, and a second channel is cleaned. One bed (0.45 acres) is cleaned by 8 men in 4 hrs., using 250,000 gals. of water. The quantity of water filtered between cleanings is about 25% less when the beds are washed instead of scraped.

At the Forest Stream plant, 60,000,000 gals. are filtered between scrapings.

Output of Sand Washers.*—In a sand filtration plant the sand is, in a way, the most important part of the filters. It is important, therefore, to secure the best sand that can be reasonably obtained. The following method of securing and preparing filter sand was used in the construction of the water filtration plant of Washington, D. C., and was described by Mr. Allen Hazen and Mr. E. D. Hardy, Trans. Am. Soc. C. E., 1906.

The contractor furnished sand from a bank at Laurel, Md., on the main line of the Baltimore & Ohio R. R., half way to Baltimore. This bank was probably of tertiary origin, and consisted of layers of clay and sand. The sand in the sand layers was of good quality, except that more or less clay was distributed through it. The layers of clay ranged in thickness from a few inches to several feet, and the mixture was such that it was not possible to take the sand without the clay.

The method of securing and preparing filter sand of the requisite cleanliness and of the quality specified was as follows: The sand was excavated from the bank with steam shovels, taking the mixed material, to a depth often reaching 20 ft. The material obtained in this way consisted mostly of sand, but large and small lumps of clay were always mixed with it, and the top soil was not separated. The proportion of the material which could not form part of the filter sand was rather large. The sand was loaded on cars, which carried it on temporary tracks to the screening and washing plant built close to the main line of the Baltimore & Ohio R. R.

The material was first dumped from the cars through a coarse grating which separated many of the largest lumps of clay. It then passed through a revolving screen, with holes about 2 ins. in diameter, which removed further quantities of clay in lumps. It was then taken by a link-belt elevator to the top of a timber trestle, and discharged into a revolving screen, with round holes having a size of separation of about 4 mm. Water jets played upon this screen and facilitated the passage of sand through it, while much fine gravel and some additional lumps of clay were removed. The specifications provided that the sand must be free from particles more than 5 mm. in diameter, and the screen secured this result. The material passing through the screen consisted of the sand, to-

*Engineering-Contracting, Feb. 20, 1907.

gether with a large quantity of clay, partly pulverized and partly in lumps, all carried by a considerable quantity of water. The mixture then passed to a series of pug-mills. The revolving arms in these broke up and pulverized the remaining clay lumps. This treatment was necessary for a material containing clay in lumps, but would be unnecessary for sand not containing such material.

The pug-mills incidentally served to separate a portion of the clay from the sand, for an excess of water entered them, and extremely dirty water was constantly wasting over their tops, while the sand was drawn out from points near the bottoms in much the same way as it was subsequently drawn from the sand washers.

The mixture of sand, clay and water leaving the pug-mills next passed to the washers. These washers, Fig. 24, consisted of three long, narrow boxes with bottoms having slopes of 1 in 6 to the point of discharge. The boxes were 16 ft. long, 24 in. wide and 18 in. deep at the upper end. There were four pipes, perforated for their entire length, in the bottom of each box, the holes opening directly downward. Water was forced through these pipes at a rate of about 1 cu. ft. per min. per sq. ft. of box area. This water went upward and overflowed into a trough running lengthwise of the box at the top. The mixed materials entered this box at the upper end, flowed through it, and were discharged at the lower end from the bottom. There were, therefore, two movements in each box; first, a movement of wash-water upward from the bottom of the box to the top and out through the waste overflow; and second, a forward movement of sand from one end of the box to the other. The upward movement of water, starting from the whole area of the bottom and overflowing from most of the area of the top, kept the sand in a semi-suspended state and practically in the condition of quicksand.

Under these conditions the larger particles of sand rapidly sank to the bottom while the finer particles were carried to the top. The sand at the bottom was in contact with the clean water as it first entered the box, while, by controlling the quantities of sand let in and drawn out, the finer particles could be forced to the top and out through the waste overflow to any desired extent. The level of the sand in the box was usually carried not more than about 6 in. below the surface of the water.

As the sand in the box was in the state of quicksand, it was possible to draw it out, through a gate placed just above the bottom at the lower end of the washer, in the form of a fluid containing very little water. Generally, 10 parts of the mixture drawn from the outlet contained 9 parts of solid sand. The mixture fell into a large hopper, from which a gate allowed it to flow from time to time into cars on a side-track below, often without further separation of water, except as it gradually drained out through the cracks in the hopper and in the bottoms of the cars.

In general, it was found that 1 cu. yd. of sand per hour could be washed for each square foot of box area, and sometimes a larger quantity was passed.

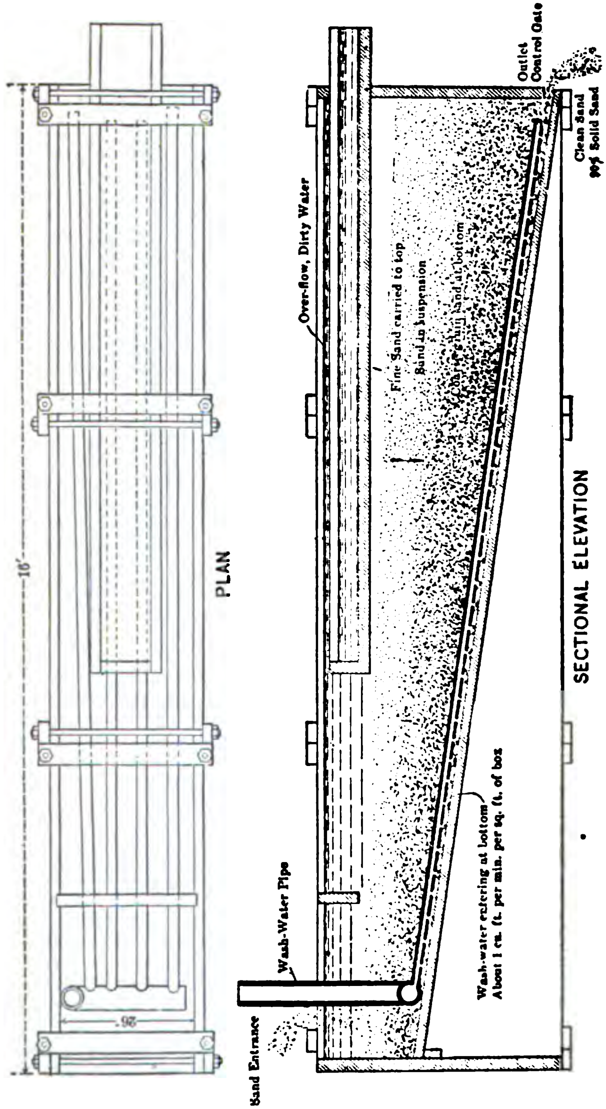


Fig. 24.—Sand Washer.

A washing box of this character was first designed by one of the writers for use in preparing filter sand at Yonkers, N. Y. The same type of box was used in preparing all the sand placed in the filters at Providence, R. I., and has also been used elsewhere.

The separation of the clay from the sand in such large quantities and so cheaply was an achievement which would hardly have been regarded as possible at the time the contract for filter sand was made, and the use of this process cheapened the sand washing very greatly, the actual cost to the contractor being far below the contract price.

Although exact figures are not at hand, it appears that the volume of water used in washing the sand was not more than five or six times that of the sand. The wash-water was obtained from a small creek nearby, and was pumped through a 10-in. pipe. After rains the water in this creek was quite turbid, but this turbidity did not interfere materially with the washing, or with the quality of the sand produced.

In a working day of 10 hours more than 900 cu. yds. of filter sand were frequently produced, and, had it been possible to handle the sand at the filters more rapidly, the plant could have worked at night, with a greatly increased output.

The specifications provided that the filtering sand should be entirely free from clay. The specification had proved sufficient in securing sand from river deposits and from sand banks of glacial origin. It did not prove satisfactory in the case of this sand, as the raw material contained large quantities of clay. The clay stuck to the particles of sand on drying, and the ordinary mechanical analysis, by sifting the material in a dry state, was inadequate to show its presence or amount.

It becomes apparent at once that a method of measuring the amount of clay in the sand must be found and used, and definite limits set to the amount of clay that could be present, which should be substantially equivalent to the requirements of the specifications.

The method adopted of determining the amount of clay was as follows: A weighed quantity of sand, usually 25 g.—but less if there was considerable clay in it, and more if there was but little—was agitated for some minutes with several times its volume of water. The sand for this purpose was taken directly from the washers and was not dried, as drying increased the difficulty of getting the clay in suspension. If the sand had dried before testing, it was necessary to keep it moist and agitate it for some time to get all the clay loose. When this was accomplished the mixture was made up to a volume of 1 liter in a graduated glass. This was allowed to stand for 1 min. The turbidity of the supernatant fluid was then taken by observing the depth below the surface that a platinum wire could be seen, by the method of the U. S. Geological Survey.

These observations were taken in the graduated glass for convenience. This was not strictly in accordance with the official instructions, but it was more convenient, and the comparative re-

sults were good. Jackson's turbidimeter was used with good results for night work, but the rod was preferred by the inspectors when it could be used. The turbidity of the water thus found was multiplied by the ratio of the volume of the mixture to the weight of sand taken. That is to say, for the quantities above stated it was multiplied by 40. The figures thus represent approximately the turbidity in the sand in parts per million by weight. One part of clay by weight actually produces about two parts of turbidity, because the particles of clay are much finer than the particles of standard turbidity, but this matter is overlooked, and the results are expressed as standard turbidity in parts per million. To get the actual weight of the clay, therefore, the figures should be divided by two.

It was decided after study that a reasonable interpretation of the specification, expressed in terms of turbidity, was represented by 4,000 parts per million, and this limit was rigidly insisted upon. Generally, the sand contained less than 3,000 and frequently less than 2,000 turbidity, the last figure corresponding to less than 0.1 per cent of actual clay by weight in the sand as delivered. That this result could be regularly secured from a bank where a considerable percentage of the total material was clay is, the writers think, a very remarkable result, indicating both an excellent apparatus and most efficient management, on the part of the contractor, and by the sand inspectors.

Part of the sand-washing plant was duplicated. This was done before the full capacity of the part first built was realized. It was intended to insure against delay in case of accident and to allow an increased output, but the first part did so well that the second part was used hardly enough to test it.

The sand was taken in cars to an elevated siding near the filters, and dumped into hoppers. These hoppers were provided with sand-gates, and carts were driven underneath and loaded from them. These carts were taken over the roofs of the filters, and the sand was dumped through the manholes. Chutes were arranged under the manholes, upon which the sand fell. This broke the force of the fall which, otherwise, might have compacted the sand to an undesirable extent, and also threw it to a considerable distance horizontally. The chutes were revolved, and in this way most of the filter sand was placed directly where it was wanted without further handling. It was necessary to place only a small part of it with shovels. This method of placing the sand in the filters is so simple and cheap that it has been adopted for regular use in replacing the washed sand in the filters.

The sand settled, on an average, about 5 per cent when it was wet and the filters were placed in service. The average depth of the sand in the filters after settling was 38 ins., but different filters were filled to different depths, so that when sand is replaced from the washers in the filters it will go first to the filters having initially the least sand, and a regular regime is thus established from the start.

Cost of Filter, Lambertville, N. J.—Mr. Churchill Hungerford gives the following relative to a small slow sand filter at Lambertville, N. J., built in 1876. There are two filter beds, each 60 x 100 ft., giving a total of 0.28 acre, and the cost was $5,600, or at the rate of $20,000 per acre. They were built in clay and not lined with concrete, but the side slopes and bottom were riprapped with stone. A puddle trench 4 ft. wide runs beneath all the embankments, averaging about 10 ft. deep. The basins are 9 ft. deep. A 12-in. vitrified pipe runs the entire length of each basin, on one side, and is fed by 4-in. vitrified pipes spaced 2 ft. c. to c. Gravel was placed around and over the pipes, and a layer of sand 2½ ft. thick. The filter delivers 225,000 gals. per day, but has a much greater capacity.

Cost of Reinforced Concrete Roof for Filter, Indianapolis.—Mr. William Curtis Mabee gives the following data relative to the cost of covering 4.8 acres of filter beds with a reinforced concrete roof resting on steel beams and cast-iron posts, built in 1905, for the Indianapolis Water Co., by day labor.

The filter beds had been in operation for a year or more, but ice and algae had caused so much trouble that it was decided to roof them, disturbing the filter sand as little as possible. The roofing cost 35½ cts. per sq. ft., including 2 ft. of cinders and a concrete parapet wall all around the roof to hold the cinders. The concrete for the roof was mixed 1 : 2 : 4, and amounts to 0.017 cu. yd. per sq. ft. The roof is a continuous slab 3 ins. thick, reinforced with ¼-in. corrugated rods spaced 3 ins. c. to c. in parallel lines, and with cross rods of the same size spaced similarly. The roof slab is supported by concrete girders, 8 ins. wide, with a depth of 10 ins. below the roof slab, and spaced 6 ft. 9 ins. c. to c. Each girder is designed as a continuous beam, reinforced with four ¾-in. corrugated rods, each bar being so bent that for three-quarters of its length it is near the bottom of the beam, and then passes along the top of the beam and over the supporting I-beam for about a quarter span; hence each bar has a length of about 1¼ times the length of the beam. These reinforced concrete beams are supported by steel I-beams. The I-beams are 18-in. (55 lb.), spaced 19½ ft. c. to c., and are embedded in concrete 10 ins. thick. The I-beams are spliced at the quarter point of the span. The I-beams are supported by 7-in. cast-iron columns spaced 20 ft. c. to c., filled with concrete. The columns rest on concrete pedestals, the top of which is 6 ins. above the surface of the filter sand. The excavation for these columns was accomplished by the aid of light steel cylinders that were sunk through 4 ft. of filter material, and then filled with concrete. The cast-iron columns are 11¼ to 12 ft. long. Being only 7 ins. diam. and spaced 20 ft. apart, there is a gain of more than 1 per cent in the effective filtering area under the roof, as compared with the ordinary brick columns 20 ins. square and spaced 14 ft. c. to c.

The use of cinders instead of earth effects a decided saving in the amount of material required for the roof, and the cinders, in

this case, cost no more than earth. The roof was designed to support the cinders and such water as they would hold. A factor of safety of 3 was adopted for the roof reinforcement, based upon 50,000 lbs. per sq. in. elastic limit of steel, and using 1 per cent reinforcement.

The iron, steel and concrete were handled by a movable cableway spanning the filter beds.

The centering was supported from the steel I-beams, by U-bolts, and was left in place 10 to 14 days, or until the concrete would ring under a hammer when struck lightly.

Cost of Seven Mechanical Filters.—Table XIV gives the first cost of 7 mechanical filter plants of the Jewell type:

TABLE XIV.

Locality.	When finished.	Capacity per day, gals.	Cost without buildings or clear reservoir.	Cost with buildings and clear reservoir.
Terre Haute, Ind.	1891	4,000,000	$30,000	$45,000 (1)
Chattanooga, Tenn.	1893	3,000,000	30,000	32,000 (2)
Burlington, Ia.	1894	3,500,000	33,000	75,000 (3)
Ottumwa, Ia.	1895	2,000,000	13,500	21,500 (4)
Danville, Pa.	1895	1,000,000	6,000	14,000 (5)
Lexington, Ky.	1895	2,000,000	......	27,000 (6)
Cedar Rapids, Ia.	1896	4,000,000	32,000	47,000 (7)
Total		19,500,000		$261,500

Notes.—(1) The buildings cost $5,000 and the clear water reservoir cost $10,000.

(2) There is no clear water reservoir.

(3) The clear water reservoir holds 500,000 gals.

(4) The settling tanks are combined with the filtering tanks, being below the filtering material. The 6 filters are housed in a brick building, 41 x 95 ft.

(5) Extra pumps, $1,000; clear water reservoir of 90,000 gals. (roofed), $7,000; it is not clear whether a building is included in the $14,000.

(6) The clear water reservoir holds 330,000 gals.

(7) Brick building, 40 x 140 ft., clear water reservoir beneath. The cost includes two 3,000,000-gal. low service pumps.

Cost of Mechanical Filter, Danville, Ill.—A mechanical filter plant built at Danville, Ill., in 1903, cost $75,000 for buildings, filters, coagulating basins, clear water reservoir, and the operating machinery. The capacity of the plant is 6,000,000 gals. per day. The filter beds have a capacity of 125,000,000 gals. per acre per day. The coagulant is lime and sulphate of iron specified not to cost more than $1.10 per million gallons when the water has "average turbidity."

Cost of Mechanical Filter and of Filtering, Norfolk, Va.—Mr. Edmund B. Weston gives the following relative to a mechanical filter plant built in 1899 at Norfolk, Va. The plant has a capacity of 8,000,000 gals. per day. There are 16 filters, each 15 ft. in diameter. At a rate of 127,000,000 gals. per acre per day, each filter has a daily capacity of 500,000 gals. The cost of the filter plant, exclusive of a 5,000,000-gal. subsiding reservoir and a 1,000,000-gal. clear water reservoir, was as follows:

Filter buildings and foundations	$ 23,342
Filters and auxiliaries	74,083
Pump for supplying filters	1,690
Electric light equipment, etc	693
Total	$ 99,808
Work upon subsiding reservoir including drainage pump	4,690
Total	$104,498

The subsiding reservoir was already in existence, being an old reservoir.

The cost of operation during the month of March. 1900, which was typical, was as follows, per million gallons:

Labor	$1.13
Coal at $3 per ton	0.86
Clearing subsiding reservoir	0.08
1.95 grains of sulphate of alumina per gal., at 1.2 cts. per lb.	3.40
Total	$5.47
Additional labor if pumping station were not adjacent to filter building	0.33
Total	$5.80

This does not include interest, depreciation and repairs, which it is safe to say, would amount to at least $3 per million gallons, if the cost of the subsiding reservoir and clear water reservoir are included.

Cost of Mechanical Filter and of Filtering, Walkes-Barre, Pa.—A mechanical filter plant (of the Jewell type) was built in 1895 at Wilkes-Barre, Pa. The cost was $122,400, including a brick building having 11,200 ft. floor area. There are 20 filter tanks, having a combined area of 2,260 sq. ft., and a daily capacity of 10,000,000 gals. There are two 50-hp. boilers, a 10 x 10 x 12-in. pump for raising filtered water for washing the filters, a 15-hp. engine for driving the sand agitators, a 6 x 10 x 12-in. air compressor for agitating the solution in the coagulant tank, and a dynamo for lighting. Sulphate of alumina is used as a coagulant, the maximum being ¾ gr. per gal.

The cost of operation per day was:

2 engineers, at $2.15	$ 4.30
2 foremen, at $1.75	3.50
2 laborers, at $1.50	3.00
Coal	0.78
Hauling coal	0.75
250 lbs. alum (for 7,000,000 gals.), at 1.75 cts.	3.82
Total, 7,000,000 gals, at $2.31	$16.15

In 1896 the labor and fuel cost of filtering 9,000,000 gals. per day was reduced to the following daily cost:

2 engineers, at $2.15	$4.30
2 washers, at $1.62½	3.25
Fuel	1.30
Oil, waste, etc.	0.11
Total	$8.96

This is $1 per million gals. exclusive of the coagulent and of interest and depreciation of plant. The first cost of the plant was $12,200 per million gals. of daily capacity.

Cost of Mechanical Filter, Asbury Park, N. J.—A mechanical filter (Continental) was built in 1894 at Asbury Park, N. J., for removing the iron from artesian well water. Its capacity is 2,000,-000 gals. per day, and its cost was $20,000, not including a brick building 45 x 45 ft. (2,025 sq. ft.), estimated to cost $1,500. This does not include a 12-ft. standpipe 125 ft. high, which receives the clear water. About 10 per cent of the total pumpage is used for washing the filters.

Cost of Mechanical Filter and Filtering, Elmira, N. Y.—Mr. J. M. Divens states that the mechanical filter plant at Elmira, N. Y., has a capacity of 6 million gals. daily, and its cost was $66,000, including building. The cost of filtering, $2.80 per million gals., to which $0.70 should be added for interest and depreciation; total, $3.50.

Cost of Water Softening.—Mr. W. B. Gerrish gives the following relative to a water softening plant built in 1905 at Oberlin, O. The plant cost $12,000, and treats 165,000 gals. per day. The water is softened by the use of lime and soda. From 6 to 17 grains of lime and 2 to 6 grains of soda are used per gallon. The two (7 x 7 ft.) pressure filters are washed twice a week. The cost of treatment averages as follows per million gallons:

Chemicals	$10
Labor, interest and depreciation	15
Total	$25

Cost of Concrete, Asphalt and Brick Reservoir Lining.—Mr. Arthur L. Adams gives the following data on the Astoria (Ore.) City Water Works: The reservoir bottom is lined with 6 ins. of concrete (laid with expansion joints), ⅜-in. of cement mortar, one coat of liquid asphalt, and one harder asphalt coat. The lining of the slopes is the same except that a layer of brick laid flat, after dipping each brick in hot asphalt, was laid on the concrete. The bricks were laid on an asphalt coating and given a final asphalt coat. The actual cost per sq. ft. was:

Slope.	Per sq. ft.	Bottom.	Per sq. ft.
6-in. concrete	$0.1187	6-in. concrete	$0.1031
1st coat asphalt	0.0100	Cement mortar finish	0.0113
Brick in asphalt	0.0889	1st coat asphalt	0.0077
2d coat asphalt	0.0131	2d coat asphalt	0.0082
Chinking crevices with asphalt*	0.0030		
Ironing	0.0035		
Total	$0.2372	Total	$0.1303

*These crevices developed near the top of the slope, due to sliding of the brick slope.

The detailed cost of this lining work was as follows:

The concrete was composed of basalt rock, quarried and crushed

near the work, of river gravel, sand and imported Portland cement. One cubic yard of concrete contained 0.9 cu. yd. stone, 0.5 cu. yd. gravel, 0.1 cu. yd. sand and 1 bbl. cement. There were 603 cu. yds. of concrete on slopes and 678 cu. yds. on the bottom. The work was well managed, each man averaging 1.84 cu. yds. per 10-hr. day, mixed and placed on the slopes, and 2.35 cu. yds. on the bottom. The men were Italians. The rock was quarried and crushed and delivered at the work (800 ft. haul) for 95 cts. per cu. yd. Sand and gravel were bought at 86½ cts. per cu. yd., and cement at $2.45 per bbl. All mixing was done by hand. There were three gangs of mixers, 6 men in a gang, supplied with materials by 9 wheelbarrow men (5 on rock, 3 on gravel and sand and 1 on cement). The 18 mixers placed the concrete for 6 men to rake and ram. Beside this force of 33 men, there were: 1 helper at the cement, 1 man tending water, 1 man sprinkling concrete already laid, 1 water-boy and 1 foreman. The gravel, sand and cement were mixed dry, then mixed wet, and stone added; the concrete was then turned three times, and once more when deposited. On the slopes a rough finishing coat of mortar was applied by taking a little mortar from the next batch. The concrete was mixed with very little water. By raking the coarse rock down the slopes and by using a straight edge before ramming, even slopes were secured.

On the bottom the ⅜-in. mortar (1:2) coat was applied by two finishers using smoothing trowels, and they were served by 4 men mixing and carrying the mortar.

On the slopes the concrete was placed in sheets 10 ft. wide from top to bottom; and on the bottom it was laid in squares, 20 ft. on a side; 2 x 6-in. planks being used to hold the free sides of the concrete. When a new square was laid adjoining an old square, the 2 x 6 pieces were removed, and replaced by a piece of ½ x 4-in. weather boarding. Two weeks later these ½-in. strips were removed so that the grooves could be run full of asphalt. The ½-in. strips should be beveled and laid with the wide edge up, or they will be removed with difficulty. The labor cost of concreting was $1.07 per cu. yd. on the slopes and 67 cts. on the bottom, wages being 15 cts. an hour.

Two grades of Alcatraz asphalt were used: the L and the XXX, or paving brand. The L grade is a natural liquid asphalt, and the XXX grade is the product of refining the natural rock asphalt with about 20 per cent of the liquid as a flux; they are sold in barrels holding 400 lbs. No asphalt was placed on the concrete until it had been in place two weeks and was dry on the surface. On the bottom of the reservoir the first coat applied was the L grade, the second coat was the XXX grade. On the slopes none of the L grade was used, because of its tendency to creep; moreover the harder asphalt when at the proper temperature runs readily and fills all crevices. The only advantage of the L grade is that it will adhere to a damp surface where the XXX will not.

For best results all work should be done in the dry summer months. All dust must be carefully swept off the concrete as it prevents bonding with the asphalt. The asphalt applied with mops made of twine, was delivered in sheet-iron buckets by attendants who carried it from two melting kettles holding 3,000 lbs. each.

The bricks used on the slopes were half vitrified and half common, due to inability to get the full number of vitrified bricks. They were submerged in a bucket of hot asphalt and placed on the slope with iron tongs; a common laborer, after a little practice, readily averaged 2,300 bricks laid in 10 hrs. A push joint was made. To secure close joints and consequent economy in asphalt, the asphalt must be kept hot enough to run like water.

The asphalt finishing coat followed the brick laying as closely as possible, to avoid delays due to rain-water standing in open joints. The slope was ironed with hot irons to improve the appearance. Overheating of the irons is apt to injure the asphalt. During hot weather the brick slid on the slope somewhat by closing up thick joints laid in colder weather; but all motion ceased in a few weeks. The advantage of asphalt lies in retarding the passage of water through brick or concrete; it does not exclude water, for an asphalt coated brick submerged in water will eventually absorb as much water as an uncoated brick.

Cost of First Asphalt Coat on Concrete Slopes (29,637 sq. ft.).

Labor:	Total cost.	Cost per sq. ft.
Building sheds	$ 5.00	$0.00017
Spreading, 91 hours at 20 cts.	18.20	0.00061
Boiling, 91½ hours at 15 cts.	13.72	0.00046
Helpers, 73½ hours at 15 cts.	11.02	0.00037
Sweeping, 49½ hours at 15 cts.	7.43	0.00025
Materials:		
Asphalt, 19,243 lbs. at $0.1225	235.73	0.00795
Fuel, 1 cord wood at $2.50	2.50	0.00009
Hauling 9.6 tons asphalt at $0.47	4.50	0.00015
Totals	$298.10	$0.01005

Cost of Asphalt Finishing Coat on Slopes (29,637 sq. ft.).

Labor:	Total cost.	Cost per sq. ft.
Building sheds	$ 5.00	$0.00017
Spreading, 95¾ hours at 15 cts.	14.36	0.00049
Boiling, 73¼ hours at 15 cts.	10.99	0.00037
Helpers, 144½ hours at 15 cts.	21.68	0.00073
Sweeping, 20 hours at 15 cts.	3.00	0.00010
Foreman, 60 hours at 25 cts.	15.00	0.00051
Materials:		
Asphalt, 25,230 lbs. at $0.01225	309.07	0.01042
Fuel, 1 cord	2.50	0.00008
Hauling, 12.6 tons at $0.47	5.92	0.00020
Totals	$387.52	$0.01307

Cost of Ironing Asphalt Slope (29,637 sq. ft.).

Labor:	Total cost.	Cost per sq. ft.
Ironers, 295.5 hours at 15 cts.	$ 44.33	$0.00150
Heaters, 75 hours at 15 cts.	11.25	0.00038
Helpers and sweeping, 34½ hrs. at 15 cts.	5.18	0.00017
Foreman, 49½ hours at 25 cts.	12.37	0.00042

Materials:		
Irons, 20 at $1.50	30.00	0.00101
Fuel, 1 cord at $2.50	2.50	0.00008
Totals	$105.63	$0.00356

Cost of First Asphalt Coat on Concrete Bottom (34,454 sq. ft.).

Labor:	Total cost.	Cost per sq. ft.
Building sheds, 25 hours at 20 cts	$ 5.00	$0.00015
Spreading, 38 hours at 20 cts	7.60	0.00022
Boiling, 37 hours at 15 cts	5.55	0.00016
Helpers, 43 hours at 15 cts	6.45	0.00019
Sweeping, 44 hours at 15 cts	6.60	0.00019
Materials:		
Asphalt, 18,490 lbs. at $0.01225	226.50	0.00658
Fuel, 1 cord	2.50	0.00012
Hauling, 9.25 tons at $0.47	4.35	0.00007
Totals	$264.55	$0.00768

Cost of Second Asphalt Coat on Bottom (34,454 sq. ft.)

Labor:	Total cost.	Cost per sq. ft.
Building sheds	$ 5.00	$0.00015
Spreading, 35 hours at 15 cts	5.25	0.00015
Boiling, 30 hours at 15 cts	4.50	0.00013
Helpers, 52½ hours at 15 cts	7.88	0.00023
Sweeping, 44½ hours at 15 cts	6.68	0.00020
Foreman, 17½ hours at 25 cts	4.38	0.00013
Materials:		
Asphalt, 19,591 lbs. at $0.01225	239.99	0.00702
Fuel, 1 cord at $2.50	2.50	0.00007
Hauling, 9.8 tons at $0.47	4.61	0.00013
Totals	$280.79	$0.00821

Cost of Laying Brick on Slopes (132,000 Bricks Dipped in Asphalt and Laid Flat; 29,637 sq. ft.).

Labor:	Total cost.	Cost per M.
Unloading brick from barge, 290 hrs. at 15 cts; foreman, 22 hrs. at 25 cts	$ 49.00	$ 0.37122
Hauling and storing, 160 hrs. at 35 cts. and 140 hrs. at 55 cts	152.43	1.15473
Laying, 561 hrs. at 15 cts	84.15	0.63750
Attendance, 1,341 hrs. at 15 cts	201.15	1.52387
Boiling asphalt, 220 hrs. at 15 cts	33.00	0.24500
Foreman, 96 hrs. at 25 cts	24.00	0.18180
Materials:		
Brick, 132 M at $7.00	924.00	7.00000
Asphalt, 93,372 lbs. at $0.01225	1,143.81	8.66516
Asphalt haul, 46.7 tons at $0.47	21.95	0.16628
Totals	$2,633.49	$19.95055

Cost of Lining a Reservoir With Asphalt.—In Trans. Am. Soc. C. E., 1892, Vol. 27, p. 629, Mr. James D. Schuyler discusses the use of California asphalt for lining two reservoirs of the Citizens' Water Co., at Denver, Colo.

The earth slopes of a reservoir were first sprinkled and rolled with a 5-ton slope roller, operated by a hoisting engine mounted on rails on top of the embankment. Slopes were 1⅛ to 1, and depth of water was 20 ft. Beginning at the bottom the asphalt was laid on the earth slopes in horizontal strips 10 ft. wide, 1¾ ins. thick, spread with hot rakes, tamped with hot tampers, and ironed with hot smoothing irons. Asphalt was hauled 2½ miles and delivered at a temperature of 250°. While the asphalt sheet was still warm, anchor spikes, of ⅛ x 1-in. strap iron 8 ins. long, were driven through the asphalt into the bank in rows 1 ft. apart. Every other row was driven flush, the alternate rows being temporarily left projecting 1½ ins., to serve as a rest for 2 x 4-in. strips of lumber, forming steps for the workmen. When the finishing coat came to be applied these spikes were driven in flush.

The bottom was coated with asphalt 1 in. thick, and after tamping was rolled with a cold 5-ton steam roller. The finishing coat of refined Trinidad asphalt, fluxed with residuum oil, was poured on hot from buckets and ironed with smoothers heated to cherry red. When first applied the irons produced a yellow smoke, and had to be moved rapidly, but thus only could a good bond be secured with the first coat.

The cost of asphalting a reservoir having a bottom area of 87,300 sq. ft. and a side-slope area of 65,300 sq. ft., or a total of 152,600 sq. ft., was as follows:

1,304 tons, 20% asphalt mastic, 80% sand, at $12	$15,648.00
15 tons, 15% asphalt mastic, 85% sand, at $10	580.00
86.21 tons liquid asphalt fluxed with oil, at $40	3,448.40
Fuel for heating irons and for steam roller	276.02
Lights	36.00
Tools	179.75
Pegirons, material and labor of cutting and dipping in asphalt	650.00
Labor	1,921.50
Use of roller 6 days	60.00
Total for 152,600 sq. ft., at 14.94 cts. per sq. ft.	$22,799.67

Mr. Schuyler informs me that, as nearly as he can remember, men were paid $1.75 per 10-hr. day, although possibly the rate was $2 a day.

The second reservoir was lined in a manner similar to the first, just described. The total area of bottom and slopes was 143,670 sq. ft., which required 1,156 short tons of the asphalt and sand mixture for the first coat; and as this mixture weighed 127 lbs. per cu. ft. after compression, the average thickness was 1.53 ins., requiring 16 lbs. per sq. ft. The finishing coat was ⅛ to ¼-in. thick, and required 1.24 lbs. of asphalt per sq. ft. The cost of lining this reservoir was as follows:

	Cts. per sq. ft.
Materials for first coat	8.98
Materials for second coat	2.48
Labor, fuel, spikes, etc.	1.99
Total cost of both coats	13.45

In preparing the mastic for the first coat 78% of La Patera asphalt and 22% of Las Conchas flux were boiled together in open kettles for 12 hrs., at 250° to 300°, with frequent stirring. Then 20% (by weight) of this mastic was mixed with 80% of sand heated to 300°, a cylinder with strong paddles being used for the mixing, which took about 2 mins. The charge was dumped into a cart, hauled to the reservoir and dumped upon a wooden platform, and thence taken in hot scoops, spread and raked. Hot rollers were then used, and they were superior to tamping and ironing. These rollers were made from sections of cast iron pipe, turned smooth on the outside, and fitted inside with a hanging basket in which a fire was maintained. For the bottom rolling a 30-in. pipe was used; for the slopes a 14-in. pipe, pulled with a ⅝-in. wire cable passing over a pulley at the top of the slope, was used.

Asphalt as a reservoir lining possesses several advantages: It will not crack even when there is considerable settlement of the embankment. If cracks do occur it is easily patched, the new material uniting perfectly with the old.

To prevent earth from crumbling and rolling down upon the partly completed asphalt, it is often wise to plaster the earth with a mortar of sand, cement and lime to a thickness of nearly 1 in., which will cost about ½ ct. per sq. ft. On this should be spread a thin coat of liquid asphalt as a binder, which would have the additional advantage of protecting the asphalt from ground water. To prevent accumulated ground water from forcing off the asphalt lining, when the water in a reservoir is drawn down, it is often necessary to provide broken stone drains back of the lining. These drains may be led to a receiving well connected with the reservoir by pipes provided with valves opening automatically into the reservoir.

Ice, 18 ins. thick, has been frozen fast to the asphalt lining all around, and the water lowered and raised again 3 or 4 ft. without damaging the lining in the least.

I am informed (September, 1904) by Mr. Geo. S. Prince, Asst. Ch. Engr. the Denver Union Water Co., that this asphalt lining has not been durable. "It has run considerably on the slopes and this has resulted in the cracking and disintegrating of the asphalt so that considerable expense has been involved in keeping it in anything like serviceable condition and we would not consider using it again in this connection, preferring rather to employ concrete linings."

Cost of Lining a Reservoir With Concrete.—Mr. G. L. Christian gives the following: In laying 3,000 cu. yds. of 1 : 3 : 6 concrete, 6 ins. deep, over the bottom of a reservoir, the wages paid were: Foreman, $2.50; laborers, $1.35, and teams, $4 a day. The cost of blasting the rock is not included, but the cost of loading, hauling and crushing is included:

	Per cu. yd.
Sand	$ .37
Natural cement	1.10
Loading and hauling stone to crusher	.25
Labor at crusher, at $1.35 a day	.20
Rent of crusher	.01
Coal for crusher	.05
Hauling stone from crusher	.15
Foreman of concrete gang	.05
Laborers concreting, at $1.35	.50
Teams concreting, at $4	.08
Total	$2.76
9% for supt., timekeeper, office help, etc.	.24
Total	$3.00

The concrete was mixed very wet.

Cost of a Concrete Reservoir Floor at Pittsburg, Pa.—Mr. Emile Low gives the following data:

The floor of the Highland Ave. Reservoir at Pittsburg, Pa., was covered in 1884 to a depth of 5 ins. with concrete, laid on a clay puddle foundation. The concrete mortar was made of 1 bbl. natural cement to 2 bbls. sand, mixed to a thin grout in wooden boxes standing on legs. Five barrels of stone (standstone) were spread on a platform of 2-in. plank, 10 x 16 ft., and the grout was poured over it, the whole mass being then turned over three times with shovels, then deposited to the depth of 5 ins. and rammed. The stone was quarried and hauled 20 miles by rail, then unloaded into small cars and hauled ½ mile to the reservoir. The sand was obtained in the reservoir limits, and cost merely the work of excavation, or 1¼ cts. per bushel.

The following was the cost of two days' work:

27 laborers, 2 days, at $1.25	$72.90
1 foreman, 2 days, at $2.50	5.00
Total, 101 cu. yds., at 77 cts.	$77.90

During one month the labor cost was:

	Total cost.
642 days, laborers at $1.35	$866.70
17 days, water-boy, at 60 cts.	10.20
22 days, foreman, at $2.50	55.00
Total, 1,302 cu. yds., at 71½ cts.	$931.90

During another month 1,425 cu. yds. were laid at 95 cts. per cu. yd., wages being $1.25 a day.

The average cost of the 7,680 cu. yds. of 1 . 2 : 5 concrete was:

	Per cu. yd.
Quarrying stone	$ .45
Transporting stone	.50
Breaking stone (2½-in. ring)	.35
1⅛ bbl. natural cement	1.80
8 bu. sand	.10
Water	.05
Labor (wages $1.25 a day), mixing and laying	.75
Incidentals	.05
Total	$4.05

The contract price was $6 per cu. yd.

Cost of Reservoir, Forbes Hill, Mass.—Mr. C. M. Saville gives the following relative to a small reservoir (Forbes Hill) at Quincy, Mass., holding 5,000,000 gals. The bottom is 100 x 280 ft., and the sides slope 1 to 1¾. The lining is concrete. The excavated earth was used to build the banks, which are 17 ft. wide on top.

The cost, at contract prices, was as follows:

30,100 cu. yds. earth excavation, at $0.38	$11,438
Rock excavation, at $2.50	52
2,337 cu. yds. concrete, at $5.25 to $8	15,045
6,822 sq. yds. plastering, at $0.25	1,706
695 sq. yds. granolithic walk, at $0.21	1,313
Seeding	21
Railing	425
Miscellaneous extras	462
Total	$30,462

For detailed cost of the concrete lining and plastering, see the following section.

The gate chamber cost $7,765.

Cost of Concrete Lining and Plastering a Reservoir, Forbes Hill, Mass.—Mr. C. M. Saville is authority for the following cost data on the Forbes Hill Reservoir, Quincy, Mass., built by contract in 1900-1901. Common laborers were paid $1.50 per 10-hr. day. There were four classes of concrete used, and their itemized costs were as follows:

Class "A"; Concrete 1 : 2½ : 4.

1.35 bbl. Portland cement, at $2.23	$3.01
0.46 cu. yd. sand, at $1.13	.52
0.74 cu. yd. stone, at $1.13	.84
25 ft. B. M. lumber for forms, at $20.00 per M.	.50
Labor, on forms	.59
Labor, mixing and placing	1.15
Labor, general expenses	.20
Total (279 cu. yds.) per cu. yd.	$6.81

Class "B"; Concrete 1 : 3 : 6.

1.07 bbl. Portland cement, at $2.23	$2.39
0.44 cu. yd. sand, at $1.13	.50
0.88 cu. yd. stone, at $1.13	.99
6½ ft. B. M. lumber for forms, at $20.00 per M.	.13
Labor, on forms	.21
Labor, mixing and placing	.97
Labor, general expenses	.15
Total (284 cu. yds.) per cu. yd.	$5.34

Class "C"; Concrete 1 : 2 : 5.

1.25 bbl. natural cement, at $1.08	$1.35
0.34 cu. yd. sand, at $1.02	.35
0.86 cu. yd. stone, at $1.57	1.35
4½ ft. B. M. lumber, at $20.00 per M.	.09
Labor, on forms	.10
Labor, mixing and placing	1.17
Labor, general expenses	.08
Total (400 cu. yds.) per cu. yd.	$4.49

floor to spring line, 2 ft. thick for 5 ft. below the spring line and 3.33 ft. thick at the base. The roof arches have a 12 ft. clear span, 2½-ft. rise, and are 6 ins. thick at the crown. The earth covering on the roof is 2½ ft. thick at the walls and 3 ft. thick at the center. The centers used in building the concrete roof cost the contractor 22½ cts. per sq. ft. if used only once. He attempted to use them several times, but the braces against some of the brick piers were carelessly removed after a portion of the centers had been taken down, and the lateral thrust of the concrete arches overthrew the piers and caused a loss of part of the roof. The cost of the reservoir to the city was $10,415.

Some of the items were as follows:

3,446 cu. yds.	earth excavation.
310 cu. yds.	rubble masonry.
503 cu. yds.	concrete masonry.
61 cu. yds.	brick masonry.
143 cu. yds.	gravel on roof.
439 cu. yds.	loam on roof.

A steel ring was embedded in the circular wall. The weight required for such a steel ring is given by the following formula:

$$W = 0.912\ D^2.$$

D being the diameter of reservoir in feet, and W being the total weight in pounds, including an allowance of 25% for splicing and rivets.

In Table XV, Mr. Coffin gives the estimated cost of covered reservoirs built with economic dimensions, and of the same general design as the one at Wellesley, Mass.

TABLE XV.—COST OF COVERED RESERVOIRS.

Capacity	—Round Reservoirs.—			—Square Reservoirs.—		
Gallons.	Diam.	Depth.	Cost.	Side.	Depth.	Cost.
250,000	60	12	$ 4,700	54.5	11	$ 4,800
500,000	75	16	7,800	69.5	14	8,100
750,000	88	17	10,500	79.5	16	11,000
1,000,000	98	18	12,900	88.5	17	13,600
1,250,000	106¼	19	15,200	99.5	17	16,000
1,500,000	115½	19	17,600	106.0	18	18,400
1,750,000	120	21	20,000	111.5	19	21,700
2,000,000	125	22	22,000	118.5	19	22,900
2,500,000	134	24	26,200	130.0	20	27,300
3,000,000	144	25	30,200	142.5	20	31,500
4,000,000	166*	25*	37,900	153.5	23	39,500
5,000,000	186*	25*	45,600	165*	25*	47,400

*These are not exactly the most economic dimensions.

The above estimates are based upon the following unit prices:

Earth excavation, per cu. yd.	$ 0.50
Concrete walls, floors and pier foundations	6.00
Concrete roof, per cu. yd.	6.50
Brickwork in piers, per cu. yd.	13.00
Plastering walls, per sq. yd.	0.25
Plastering floor, per sq. yd.	0.15
Gravel on roof arches, per cu. yd.	1.00
Steel ring, per lb.	0.05
Centers, per sq. ft. of reservoir area	0.15

Cost of Small Covered Reservoir, Portersville, Calif.—Mr. Phillip E. Harrows gives the following data relative to a 100,000-gal. reservoir built in 1904 for the waterworks at Portersville, Cal.

The work was done by day labor, at 20 cts. per hr. The reservoir is 50 ft. diam., 7 ft. deep, lined with 4 ins. of concrete on the bottom and 12 ins. on the sides. It is roofed with 2 x 10-in. stringers, 4 ft. apart, supporting 1½-in. plank. The ends of the stringers rested on the concrete walls and on an 8 x 10-in. girder which ran across the center of the reservoir and was supported on a pier at the center. The excavated material was a heavy clay, loaded with picks and shovels into wagons. The excavation averaged 4 ft. deep, and the embankment was 4 ft. high.

The cost was as follows:

330 cu. yds. excavation, at 58.6 cts.	$ 191.08
300 cu. yds. hauled ¾ mi., at 20.4 cts.	53.98
75 cu. yds. concrete (labor, $3.03, and materials, $5.31), at $8.34	624.74
35 squares plaster finish at $2.92	102.45
4,000 ft. B. M. roof, at $45.49	181.96
Trimming outer slopes	18.70
Total	$1,172.91

The plaster labor cost $0.57 per square on the bottom and $1.12 on the vertical sides.

The roof labor cost $12.43 per M, wages of carpenters being $3 to $4.37.

Cost of a Covered Reinforced Concrete Reservoir.—In Gillette and Hill's "Concrete Construction—Methods and Cost," pp. 589 to 597, the design of a small, square, covered reservoir (30 x 31 ft.) is given, together with detailed costs and methods of construction, of which the following is a very brief abstract. The reservoir is 12 ft. deep and holds 75,000 gals. There were 580 cu. yds. of earth excavation and 83 cu. yds. of concrete. The cost of the concrete was:

1⅓ bbls. cement, at $1.12	$ 1.49
1 cu. yd. stone	1.86
½ cu. yd. sand	0.60
Steel for reinforcement	4.76
Forms, 100 ft. B. M., at $18.30	1.85
Labor on forms	2.41
Labor on concrete and steel	2.65
Total	$15.62

The excavation cost the contractor 90 cts. per cu. yd.

The total cost of the reservoir to the contractor was $2,362, but it leaked so badly that he was subsequently compelled to excavate all around and build a brick wall (1 brick thick) a few inches from the concrete and fill in between with rich cement mortar. This additional and unexpected work cost $1,240 for labor and materials.

Cost of a Covered Reinforced Concrete Reservoir, Fort Meade, S. D.*—Mr. Samuel H. Lea gives the following:

The construction of a 500,000-gallon reinforced concrete reservoir

**Engineering-Contracting*, Feb. 27, 1907.

at Fort Meade, S. D., while not comprising any features of unusual interest, was, nevertheless, an interesting work from an engineering as well as an economical point of view. The writer, who was in direct charge of the work, believes that an analysis of the various items of cost and a brief description of the methods employed will be of interest to engineers and others interested in concrete work.

The general design of the structure was furnished by the Quartermaster-General, U. S. Army, and the details of reinforcement were worked out by the firms offering bids. The successful bidder submitted a design embodying the use of expanded metal and corrugated bars, this form of reinforcement being furnished by the

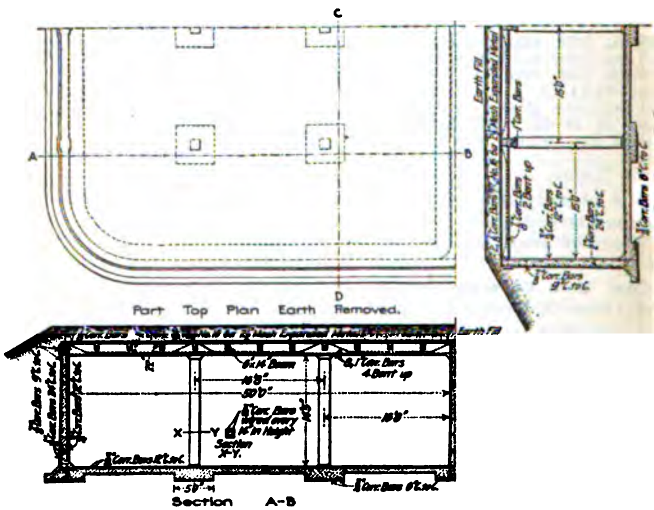


Fig. 25.—Reinforced Concrete Reservoir.

St. Louis Expanded Metal Fireproofing Co., of St. Louis, Mo. As shown in Fig. 25, the reservoir comprises two compartments of equal size, divided by a partition wall. Each compartment is 50 x 60 ft., inside dimensions, with rounded corners. The roof is a flat slab, 3 ins. thick, resting upon girders, these girders being supported by columns of a square cross-section.

Reinforcement.—The reinforcement is rather heavy, especially for the walls. As the latter are thin, the metal reinforcement occupies a relatively large portion of the wall space. The reinforcement consists of corrugated bars for the footings, floor, walls, columns, beams and roof girders, and expanded metal for the roof slab. The bars were of four different sizes: ½-in., ¾-in., ⅞-in. and 1-in., and of different lengths, varying according to the location where used. In

the floor the reinforcement consisted of ¾-in. bars laid crosswise in two layers and spaced 12 ins. apart in each layer. In the walls the reinforcement was placed close to both inner and outer faces. Near the inner face a row of upright, ¾-in. bars, spaced 12 ins. between centers, extended the entire length of enclosing and partition walls. Horizontal ½-in. bars, 24 ins. between centers, were placed against these uprights. Near the outer wall face ¾-in. upright bars were used, spaced 9 ins. between centers; and the horizontal reinforcement was of ½-in. bars, 24 ins. between centers. In the footings two layers of ¾-in. bars were used. These were laid crosswise and spaced 6 ins. apart in each layer.

Concrete.—The specifications required broken stone of hard consistency, not larger than a ¾-in. cube, and clean, sharp sand, the composition of the concrete to be one cement to two sand and four stone. These proportions were used throughout the work. Colorado Portland cement was used for the greater part of the work. Towards the finish a carload of Iola, Kansas, Portland cement was used. Both cements showed up well under frequent tests and gave excellent results in the work. The sand was obtained from a pit about three miles distant; it was of medium quality and fairly clean. The stone used was obtained partly from a limestone quarry situated at some distance from the reservoir site; but the greater portion of the supply was obtained from boulders found on the surface in the vicinity.

Excavation.—The reservoir was built so that about half of its height was below the natural level of the ground. The excavation was made in coarse gravel mixed with some sand and clay, the material being handled with teams and scrapers. The force employed in excavating consisted usually of four or six teams and about the same number of men in addition to the drivers. The men were paid $2.50 per 10-hour day and the wage for team and driver was $5 per day. A portion of the material was removed by drag scrapers, but the bulk of the excavation, consisting of compact gravel mixed with small boulders, required the use of wagons. The material was loosened by plow for scraper work for the upper portion of the excavation. It was found later, however, that better headway could be made by loosening the material with picks and shoveling it into wagon by hand. The total volume of material excavated was 2,275 cu. yds. at a cost of $1,114.75, or 49 cts. per cu. yd., divided as follows:

	Per cu. yd.
Loosening and loading	20 cts.
Hauling and depositing	25 cts.
Supervision, tools, etc.	4 cts.
Total	49 cts.

After the excavation was completed the bottom of the pit was compacted with a heavy roller, then the excavations for wall and column footings were carefully made by hand.

Concrete Work.—The concrete was mixed by hand on a movable platform; its composition is given above.

A concrete gang consisted of four men who were each paid $2.75 per day. They wheeled the materials from the supply piles to the mixing platform, mixed the concrete and deposited it in place. During the construction of the footings and floor two concrete gangs were employed, but after the walls were started one gang only was required for concrete work; the other gang was then put to work assisting the carpenters.

The sand and stone were wheeled to the platform in iron wheelbarrows of 2½ cu. ft. capacity. The cement was in ¼-bbl. sacks and each sack was taken as 1 cu. ft. Each batch of concrete contained the following quantity of material:

2½ sacks of cement	2½ cu. ft.
2 wheelbarrows of sand	5 cu. ft.
4 wheelbarrows of stone	10 cu. ft.

The quantities of sand and stone were adjusted so as to form the proper proportion for making a dense concrete. From time to time as the work progressed, experiments were made by the writer to determine the percentage of voids both in the sand and the crushed stone; and, in this way, uniformity in composition was secured for the concrete. The mixture was made quite wet in order to insure a free flow around the reinforcing bars. On account of the narrow space inside the forms and the number of reinforcing bars therein care was taken to cause the mixture to be well distributed throughout. The wet concrete was well spaded in an effort to secure a smooth surface next to the forms. This was generally accomplished, but some rough places which showed after the removal of the forms required patching up.

In constructing the footings some concrete was first deposited in place and the metal reinforcement was embedded therein. For the floor reinforcement the lower bars were carefully embedded in the concrete after it had been brought to a suitable height; the upper bars were then placed crosswise upon the lower ones and kept in position until the remainder of the concrete had been deposited around and over them. In the wall footings a depression or groove, several inches deep, was left under the wall space for its entire length. This insured a good bond between the wall proper and the footing.

The concrete floor in each compartment was built in one continuous operation, the object being to secure a practically monolithic construction. The lower reinforcing bars in the floor were embedded at the proper depth in the fresh concrete and the upper bars were then placed crosswise upon the lower ones; the two sets were then wired together at a sufficient number of places to prevent displacement while the remaining concrete was being deposited around and over them.

Placing Reinforcement.—The reinforcement for the walls and columns was erected in place upon the footings and formed a steel skeleton around which the forms were erected. The upright bars in the walls were held together and at the proper distance apart by means of templets consisting of wooden strips in which holes were bored at suitable intervals to receive the bars. These templets

were maintained in a horizontal position and were moved upward as the concrete advanced in height. The horizontal reinforcing bars were wired in place to the upright bars; they were placed in position ahead of the concreting as the wall was built up.

The corrugated bars in beam and girders were placed in position in the forms and held up by blocks which were removed as the forms were filled with concrete. The expanded metal reinforcement for the roof slab was placed so as to be close to the lower face of the slab, but far enough up to be entirely enveloped in the concrete.

Form Construction.—The wall forms were made of 2-in. planks, surfaced on the inner side and placed horizontally on edge. They were held in place by 4 x 4-in. posts spaced at intervals of about 4 ft., in pairs on opposite sides of the wall. The posts were firmly braced on the outside; they were prevented from spreading by connecting wires passing through the wall space between the edges of adjacent planks. At the rounded corners of the reservoir the pairs of posts were spaced about two feet apart and the curve was made by springing thin boards into place to fit the curve and nailing them to the posts. The posts were high enough to reach to the top of the wall; the siding was built up one plank at a time as the concrete work progressed. Column forms were made of 2-in. planks on end, extending from floor to girder. Three sides were enclosed and one side was left open to receive the concrete; this side was closed up as the concreting advanced in height.

The beam and girder forms were open troughs of the required dimensions, made of 2-in. plank, surfaced on inner faces. The form of centering for the roof slab consisted of a smooth, tight floor of 2-in. planks, extending between the open tops of column, beam and girder forms over the entire area between enclosing walls of the reservoir. The centering and the beam and girder forms were supported by 6 x 6-in. posts resting upon the floor below.

The regular carpenter gang consisted of a foreman carpenter at $5 per day, a carpenter at $3.50 per day, and two helpers at $2.75 per day. During the early concrete work of making footings and floor, where forms were not required, the carpenter force was employed in erecting the steel skeleton for the walls. The upright bars were placed in position and secured by temporary wooden stays extending from the upper portion of bars to the surface of ground outside of excavation. These stays were removed after concreting had advanced to a sufficient height to hold the steel securely in place.

Cost of Concrete Work.—The wages paid the concrete gang which mixed and placed all the concrete and the carpenter gang which constructed and erected the forms and placed the reinforcement have been given above. The costs of construction materials on the site were:

Cement, per barrel	$ 2.57
Sand, per cu. yd.	1.80
Stone, per cu. yd.	3.15
Lumber, per M ft. B. M.	27.50

The quantities in the completed concrete structure were as follows:

	Cu. yds.
Total volume of concrete in reservoir	704.71
Total volume of steel reinforcement in reservoir	5.57
Total volume of material in completed structure	710.28
Volume of material in structure exclusive of roof slab	648.35
Volume of material in roof slab	61.93
Total	710.28

The cost of the structure per cubic yard of concrete, exclusive of the roof slab, was as follows:

Item.	Per cu. yd.
Crushed stone	$ 3.168
Sand	.842
Cement	3.859
Reinforcement	4.959
Labor, mixing and placing concrete	1.721
Forms, labor and material	2.960
Total	$17.509

In constructing the roof slab the expanded metal reinforcement raised the unit cost. For this portion of the work the costs were:

Item.	Per cu. yd.
Expanded metal reinforcement	$ 5.241
Other items, same as above	12.550
Total	$17.791

Plastering and Waterproofing.—According to the requirements of the specifications the floor and the inside surface of reservoir walls were covered with a coating of cement mortar composed of one part Portland cement and one part sand. The wall plastering was from ½ in. to ¾-in. thick; it was applied in two coats. The floor finish was laid in alternate strips about 1 in. thick and 3 ft. wide. After the strips first laid had hardened the remaining strips were laid, the edges being grouted to insure tight joints.

The outside of walls and roof was covered with a coating of tar which was heated in an open kettle to a temperature of about 360° F. and then applied with a brush or mop.

The cost of wall and floor plastering was 44.4 cts. per square yard, itemized as follows:

Cement	26.4 cts.
Sand	2.6 cts.
Labor	15.4 cts.
Total	44.4 cts.

The cost of outside waterproofing was 4 cts. per square yard, distributed as follows:

Material	2.5 cts.
Labor	1.5 cts.
Total	4.0 cts.

Backfilling.—The entire structure, after completion, was covered with earth to a depth of 2 ft. above the roof, sloping on all sides to the natural surface of the ground. The earth composing this fill was handled by means of teams and scrapers; this method

caused the material to be compacted firmly in place and at the same time afforded a good test of the rigidity and strength of the roof.

The backfill gang consisted of four teams and from four to six laborers in addition to the drivers. Drag scrapers were used to move the material from the spoil banks and place it over and around the reservoir. Part of the material was side dumped from runways and shoveled to place between the walls of reservoir and sides of excavation. This material was carefully tamped and compacted as the filling progressed. The wage of team and driver was $5 per day, and for laborers for this work, $2.50 per day of ten hours.

The amount of backfilling was 2,039 cu. yds. and its cost was 30 cts. per cubic yard, distributed as follows:

Loosening and loading materials............	12 cts.
Hauling and depositing.....................	17 cts.
Supervision, tools, etc....................	1 ct.
Total	30 cts.

Summary of Costs.—The total cost of the completed reservoir, exclusive of pipe connections with water mains, was $15,068.76. The cost of the various items was distributed as follows:

Main structure, 648.35 cu. yds., at $17.509..	$11,351.96
Roof slab, 61.93 cu. yds., at $17.91........	1,101.79
Ventilators, doors, stepping irons, etc.......	164.08
Plastering, 1,517 sq. yds., at 44.4 cts........	673.08
Waterproofing, 1,285 sq. yds., at 4 cts.......	51.40
Excavation, 2,275 cu. yds., at 49 cts.........	1,114.75
Back fill, 2,039 cu. yds., at 30 cts..........	611.70
Total	$15,068.76

While some of the cost items are apparently high when compared with the cost of similar work in other places, it should be remembered that the isolated locality and the local conditions were unfavorable for low cost. Owing to the isolated location of the reservoir with respect to large markets and also to local sources of supply the cost of material and labor was quite high. All construction material, except some of the stone for crushing, had to be hauled over a mountain road from 3 to 4 miles to the top of the hill selected for the reservoir site. Labor was scarce and commanded a wage of $2.50 per day for ordinary work; the laborers mixing concrete were paid $2.75 per day. Another source of considerable expense was the high cost of lumber and carpenter work on the forms. On account of the thinness of the walls and roof, the cost of lumber and labor required per cubic yard of concrete was considerable. A part of the lumber was used the second time in forms, but it was found impracticable to delay the work by waiting for the concrete to harden before beginning the new portions of the walls. This lumber was sold after the completion of the work, but the salvage was inconsiderable, amounting to less than 10 per cent of the original cost.

The writer kept a record of cost of the various items of material and labor entering into the construction of this reservoir. This

record was verified by comparison with the vouchers and pay rolls of the contractor and was made as complete and accurate as possible. From these data the above statements of construction cost have been compiled.

Cost of Concrete Reservoir, Pomona, Cal.*—Mr. Charles Kirby Fox gives the following:

The concrete reservoir herein described was erected in the summer of 1904 on Point Lookout, Ganesha Park, Pomona, Cal. It was designed by Mr. Geo. P. Robinson, City Engineer, and Mr. Albert Simmons had the contract. The writer was in direct charge of construction.

The reservoir is oval in form (Fig. 26), being 77.7 ft. by 40.7 ft. over all. It is 12 ft. deep and the floor has a slight slope to the

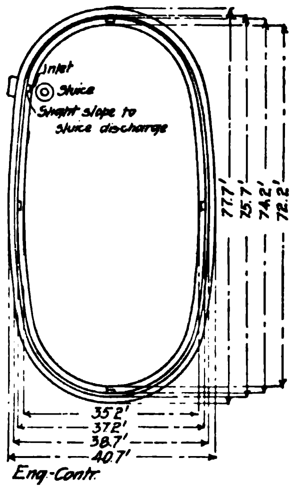


Fig. 26.—Concrete Reservoir.

sluice box. Iron ladders are placed in each of the quarter points. The inlet and overflow pipes are near the top of the walls, the discharge pipe is 12 ins. above the bottom of the reservoir and the sluice pipe is set in a bowl 3 ft. in diameter and 4 ins. deep. It is the lowest part of the reservoir.

The walls (Fig. 27) are 12 ft. high. They were designed to be 6 ins. thick at the top and 15 ins. thick at the bottom and to be connected with the bottom of the reservoir with a 12-in. radius. The bottom is 4 ins. thick. Before the walls were started it was decided to add a 6 x 30-in. ring to the outside of the top, making the

*Engineering-Contracting, April 15, 1908.

top 12 ins. wide. The joint connecting the walls with the bottom was put in about 12 ins. from the inside edge of the radius.

Around the sluices and inlet and outlet pipes a larger mass of concrete was used. The finish was ½-in. thick and was waterproofed.

The contract price of the reservoir was	$1,625.00
Extra concrete in ring, 8.3 cu. yds	60.90
Extra valve, screws, etc	16.00
	$1,701.90
Include valve box changed	$ 25.00
Cost of reservoir	1,726.90

Excavation.—The greater part of the excavation of the oval, about 77 x 40 ft., and the tunnel was done by the city by force account. I

Fig. 27.—Concrete Reservoir Wall.

have no records of the costs of this part of the work. The contractor trimmed down the sides and bottom of the reservoir, in all about 5,000 sq. ft., at a cost of $71.60, or 1½ cts. per sq. ft.

Pipes, Valves, Etc.—The pipes, valves, etc., as provided in the specifications cost $455.52 and the extra valve sets installed cost $16. The laying of the pipe cost $9.70. The tunnel excavation to get down to grade cost $52.38, making a total of $533.60. This includes 5 6-in. Ludlow valves, 270 lin. ft. of heavy 6-in. cast-iron pipe and 80 ft. of 6-in. vitrified pipe, all installed.

Cleaning Up—The contractor mixed the concrete for the walls on the floor of the reservoir and to clean out his old concrete cost him $22.25. The final clean up cost him $7.00, making a total cost for cleaning up of $29.25.

Concrete.—The concrete was specified to be 1 part cement, 2 parts sand and 4 parts gravel (pea size to 2-in. ring). As put in, a cement-barrel was filled and emptied six times with the bin run of sand and gravel and four sacks of cement (1 bbl.) were emptied on top of it; it was then turned wet. The costs per cu. yd. were:

	Per cu. yd.
Labor	$1.09
Cement, 1.08 bbl., at $3, delivered	3.23
Sand and gravel, at $1	0.93
Water (had to be pumped)	0.34
Forms, labor and lumber	0.76
Total	$6.35

The wages paid labor were $1.75 and $2 per day, foreman mason $4 per day. Carpenters were paid 43 cts. per hour and lumber cost $33 per M ft. B. M. A 9-hour day was worked.

Finish.—The ½-in. finish was specified to be 1:1, but that did not work well, so we increased the amount of sand. It was waterproofed. It was mixed very thoroughly with 35 lbs. alum at 6 cts. per lb., and then the water, containing 35 lbs. good potash soap per cubic yard of mortar was added. The finish cost:

	Per cu. yd.
Materials	$14.45
Labor, mixing and applying	11.90
Total	$26.35

On the finishing there were two masons at $4 plastering and enough laborers to keep them supplied with mortar. The completed floor cost 9 cts per sq. ft.

Summary of costs:

Cement, at $3 per bbl.	$ 481.50
Sand, at $1 per cu. yd.	113.30
Soap and alum, at 6 cts. per lb.	21.00
Water	43.00
Timber	30.00
Labor and superintendence	361.35
Pipe laying (contract price)	533.60
Total	$1,583.75

The reservoir has now been in use 3¼ years and has given excellent satisfaction. Only a few hair cracks have appeared on the surface and none of the plaster has scaled off.

Cost of Storage Reservoir, Hagerstown, Md.*—In 1902-3 the water supply of Hagerstown, Md., was improved by the construction of a storage reservoir to impound the waters of the two streams known as Warner's Hollow Creek and Raven Rock Creek. The works were designed and constructed by the American Pipe Manufacturing Co., of Philadelphia, Pa., Mr. J. W. Ledoux, M. Am. Soc. C. E., Chief Engineer.

Earth Dam and Accessories.—The general construction of the earth dam is shown by the section of Fig. 28. Owing to scarcity of

**Engineering-Contracting*, Oct. 10, 1906.

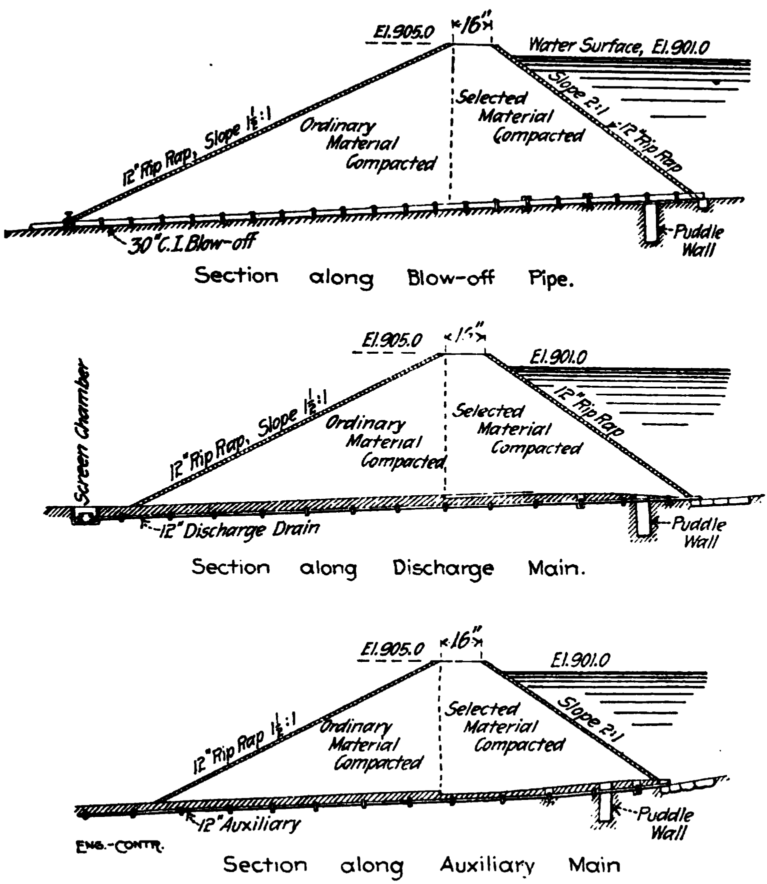


Fig. 28.—Sections of Earth Dam.

available material only the upstream half of the dam and the puddle walls were made of selected material; the downstream half of the dam was made of earth and loose rock. The main puddle wall varied from 5 to 10 ft. in width and from 6 to 20 ft. in depth, and contained 1,602 cu. yds. of material; the secondary puddle wall was narrower and shallower, containing only 712 cu. yds. of material. Both slopes of the dam are riprapped and it is pierced by a 30-in. cast-iron pipe blow-off and two 12-in. cast-iron supply mains. There was also some 1,286 cu. yds. of 3½-ft. thick dry rubble retaining wall built in connection with the dam work. The costs of these several items of the dam work are given from figures furnished by Mr. Ledoux, as follows:

Dam.—There were 93,200 cu. yds. of embankment built at a total cost of $60,532, or $0.65 per cu. yd. The several items of cost were as follows:

Items.	Per cu. yd.
Foreman	$0.0243
Hauling	0.2694
Labor	0.2252
Sprinkling	0.0144
Picking stones	0.0192
Trimming slopes	0.0080
Tools, blacksmithing, powder, etc.	0.0479
Superintendence and engineering	0.0354
Protecting for winter	0.0056
Total	$0.6494

Rip-rap.—The embankment slopes were rip-rapped with stones of ½ cu. ft. or less, placed by hand to fairly uniform thickness, after which broken stone of 3 or 4-in. sizes were spread on top and trimmed to an even slope. Altogether 3,844 cu. yds. of rip-rap stone and 1,882 cu. yds. of broken stone were placed at a cost of $5,059.69, or $0.884 per cu. yd.

Puddle Walls.—The two puddle walls aggregated 2,314 cu. yds. of puddle, the main wall having 1,602 cu. yds. and the secondary wall 712 cu. yds. The puddle was deposited loose and then flooded with water and tramped by men with rubber boots. When the top of the puddle reached a level about 3 ft. from the natural surface of the ground the amount of water was diminished to just enough to permit the clay to be tamped with rammers weighing about 20 lbs. The cost of the puddle walls was as follows:

No. 1.	Per cu. yd.
1,602 cu. yds. excavation	$1.02
Placing puddle	0.60
Tools, etc.	0.48
Total	$2.10

No. 2.	
712 cu. yds. excavation	$0.98
Placing puddle	0.80
Crushed stone in puddle	0.26
Pumping, tools, etc.	0.40
Total	$2.44

Masonry Walls.—The cost of these was:

	Total.	Per cu. yd.
Masonry cut-off walls, 52 cu. yds.	$ 262.34	$5.04
Dry retaining wall, 1,286 cu. yds.	$1,601.53	$1.245

Gate House.—The gate house cost $951.76, made up of the following items:

Concrete, 2½ cu. yds.	$ 13.20	$5.28
Rubble masonry, 15 cu. yds.	93.41	6.23
Broken range masonry, 24 cu. yds.	534.07	23.07
Red tile roof, complete	311.08	....
Total	$951.76	....

Blow-Off Pipe.—The 30-in. cast-iron blow-off pipe through the dam cost $1,761.79, or $5.96 per lin. ft., made up of the following items:

Items.	Per lin. ft.
Pipe	$4.00
Excavation	0.36
Filling	0.23
Freight, hauling and laying	1.17
Total	$5.76

Spillway.—The spillway contained 1,224 cu. yds. of 1:3:5 concrete masonry. Its total cost was $9,820.43, made up of the following items:

Concrete	$6,457.72
Top lining of 1-in. yellow pine	918.05
Excavation	1,830.90
Rip-rap on slopes above walls	78.44
Timber, crib at foot	535.32
Total	$9,820.43

The concrete work, 1,224 cu. yds., cost $5.25 per cu. yd., made up as follows:

Item.	Per cu yd.
Cement, 4.82 bags	$1.795
Sand	0.860
Stone	1.081
Labor	0.971
Tools, forms, etc.	0.541
Total	$5.248

Raven Rock Creek Intake.—To bring the water from Raven Rock Creek to the main storage reservoir a masonry intake dam was constructed on that stream, and from this dam a 30-in. terra cotta pipe line was constructed to the storage reservoir. The cost of the intake dam was $3,223.89. The itemized cost of the masonry work was:

Item.	Per cu. yd.
Excavation, 145 cu. yds.	$ 0.92
Rubble masonry, 158 cu. yds.	12.45
Concrete coping, 14 cu. yds.	13.21

The 30-in. pipe line is composed of extra heavy terra cotta pipe, with deep bells corrugated on the inside, furnished by A. N. Pierson,

New York, N. Y. It was 2,244 ft. long and cost, complete, $8,932.05. The itemized cost per foot was as follows:

Item.	Per lin. ft.
Pipe	$2.486
Cement for joints	0.057
Jute for joints	0.068
Trench, tools, etc.	1.370
Total	$3.981

Grubbing and Clearing.—The reservoir area of 15.1 acres had all trees and brush cleared off and all stumps grubbed up. The trees were generally removed by blasting. A force of about 20 men was worked, their wages being $1.50 per day. No record was kept of the area cleared per day, but the cost of clearing and grubbing is given as $107.13 per acre. The costs of two floodwood racks were $30.74 and $21.66; both were constructed as follows: Two heavy logs were laid horizontally across stream, one about 3 ft. above the bottom of the stream and the other about 8 ft. above the bottom and parallel to the first, but upstream, so as to make a slope of about 1 on 1. To these two logs were spiked 6-in. timbers reaching down to the bed of the stream. The transverse logs were supported against the roots of trees and all the timber was rough stuff, such as could be obtained on the site—chestnut, oak or spruce. While the work was in progress water was supplied by means of 1,776 ft. of rectangular trough, composed of three 12-in. posts nailed together and laid at a grade of 1 per cent. Considerable trestling was necessary. This trough cost $303.93, or 17.1 cts. per lin. ft.

Cost of a Wooden Covering for Reservoir, Quincy, Ill.—Mr. Don R. Gwinn gives the following:

The reservoir was 415 x 317 ft. at top, 26 ft. deep, inside slopes 1½ to 1. A vegetable growth had given much trouble, so the reservoir was roofed over in 1898 at a cost of 4 cts. per sq. ft., the price of lumber being at that time only $15 per M. There were 260,000 ft. B. M. used (or 2 ft. B. M. per sq. ft.), and 38 kegs of nails at $1.85 per keg. The pedestal piers or foundations for the posts were of brick ($7 per M), 21 ins. sq. at the base, 16 ins. at the top, 18 ins. high and capped with a limestone slab 12 x 12 x 6 ins. (43 cts. per cap). A ¾ x 3-in. dowel pin was let into each cap 1¼ ins. The posts were 6 x 6-in. x 22 ft., spaced 14 ft. in one direction and 18 ft. in the other. They were capped with 6 x 6-in. caps, or girders, 18 ft. long. On these caps were laid 2 x 6-in. joists or stringers 14 ft. long spaced 4 ft. c. to c.; and on the stringers were laid 1-in. roofing boards (1 x 10 in. x 16 ft.). These boards were laid north and south to exclude sunlight from the cracks as much as possible.

Two posts and a cap were framed and fastened together on the ground, and sway braced with two braces of 2 x 6, and then upended. Joists were then shoved out from the completed part of the roof, and laid flat upon the caps; two joists being thus laid upon, and nailed to, each end of the cap, to serve as walking planks for the workmen. The joists were then spaced properly by means of

gages, and then braced with 2 x 4-in. "bridging." White pine was used throughout, all the dimension stuff being No. 1, and the roofing boards No. 2. Of the total surface of the roof, 25% is trap doors.

In the section on Timberwork will be found further data on the cost of wooden coverings for reservoir. See the index under "Timberwork, reservoir roof."

Cost of a Reservoir Embankment.—The Tabeaud Dam in California is an earth embankment 100 ft. high, containing 370,000 cu. yds. of embankment. Mr. Burr Bassell is authority for the following:

The dam was built by contract in 1901, the contract price being 40 cts. per cu. yd. During the months of August, September and October more than 2,000 cu. yds. were built per working day (53,000 cu. yds. per month). Mr. Bassell states that the maximum force was 233 men and 416 horses and mules. Fresno scrapers were used to load wagons through "traps." There were 4 horses on each fresno and 4 horses on each wagon. Assuming $1.50 per day for laborers and $1.00 per day for horses, we have a daily cost of $716, or nearly 36 cts. per cu. yd., the output being 2,000 cu. yds. per day. The wagons, tools, etc. (exclusive of horses) were worth about $16,000. Allowing 3% per month for interest, depreciation and repairs, the daily plant charge would be about $20, or 1 ct. per cu. yd. Allowing 5% for general supervision and overhead charges, we have nearly 2 cts. more per cu. yd., or a total cost of 39 cts. per cu. yd.

The average haul was ¼ mile.

The earth (a clay mixed with gravel) was spread in 6-in. layers, sprinkled and rolled. To spread the 2,000 cu. yds. of embankment daily, there were 3 road graders operated by 6 horses and 2 men on each grader. There were 2 rollers, each operated by 6 horses and one driver. There were 2 harrows, and, while Mr. Bassell does not so state, presumably 4 horses and a driver to each harrow. At $1.50 per 10 hr. day for each man and $1 for each horse, we have following cost:

	Per cu. yd. Cts.
Spreading	1.5
Sprinkling	0.8
Harrowing	0.6
Rolling	0.8
Total	3.7
Loading and hauling	32.3
General expense (estimated)	2.0
Plant charge (estimated)	1.0
Total	39.0

Test pits dug in this dam showed a weight of 133 lbs. per cu. ft. of compacted earth.

The above given yardage relates to the yardage in the embankment, not in the barrow pits.

The rates of wages are merely assumed for illustration. It is probable that laborers received $2 per day at that time and place.

Cost of a Concrete Core Wall.*—This article covers the construction of 2,184 ft. of core wall, being a portion of a wall which will ultimately be 2¼ miles long. This wall was built along the toe on the pool sides of a rock-fill dam in a trench excavated to solid rock. The face of the wall has a batter of 3½ in 12 and the back conforms to the face of the side of the trench below water and is practically vertical above water, being 2 ft. wide on top. Level with the top a 6-in. concrete apron extends back 20 ft. over the top of the rock-fill dam. The wall varies in height from 10 to 21 ft. It was built of 1 : 5 gravel concrete and is reinforced as follows: A longitudinal line of old steel bars was placed in the center of the wall 6 ins. below the top. Over this horizontal bar were hooked vertical bars spaced 5 ft. apart. This reinforcement was used principally to anchor down any pieces of the wall top which might break away.

Forms.—As fast as the dipper dredge opened the footing trench to rock, 2-in. holes 10 ft. apart were drilled into the ledge. Uprights of 6 x 8 in. timbers having 2-in. rods 5 ft. long bolted to the bottoms were erected by inserting the rods in the drilled holes and bracing the tops back to posts set into the rock-fill dam. The uprights were set to the inclination of the face of the wall. Waling pieces, 6 x 6 ins. x 16 ft. were connected several end to end by bevel joints, with one bolt in each so the joint would be flexible. The several lengths of waling pieces were thus connected inside the uprights. A vertical plank was then bolted to the waling near a joint, and by it the joint was pushed down under water 3 ft., and a second waling was bolted to the plank at the surface of the water. Other planks were then bolted to the first waling at the joints on each side of the joint first sunk, and these joints were in turn pushed down 3 ft., permitting the second waling to be bolted to the planks. In this manner one waling after another was added at 3-ft. intervals until the first waling had been pushed down to rock. The walings were not fastened to the uprights, as the up-thrust of the water pushing them against the slant of the uprights held them fast.

The lagging consisted of vertical 2 x 12-in. planks, set close inside the walings; these planks were nailed to the topmost waling, but were not fastened to the lower walings.

The forms were built around curves without alterations, as the one-bolt waling joints gave considerable flexibility. Ordinarily, the wall was concreted in alternate 30 to 50-ft. sections. The forms were built continuously in advance, and torn down behind as fast as the concrete set. At the ends of sections of wall, transverse bulkheads were built inside the form and bonding recess forms fastened to them. To remove the forms the braces from the tops of the uprights were unbolted and the whole form was pushed away from the wall and taken apart. As the forms were not nailed, except at one point, as noted above, the lumber was but little damaged, and, with the addition of a small amount of lagging,

**Engineering-Contracting*, Mar. 10, 1909.

there is enough lumber remaining from the form-work for the first 2,184 ft. of wall to build the remainder of the wall. The form lumber was used from three to four times on the portion of the wall that is now completed.

Concreting.—The concrete mixing and handling plant was mounted on an 18½ x 100 ft. barge. On one end of the barge was a ¼ cu. yd. Chicago concrete mixer with a gravel supply bin mounted overhead. On the opposite end of the barge a stiff-leg derrick, operated by a bull wheel, was erected. This derrick handled the gravel from stock barges moored alongside to the supply bin over the mixer, and also handled the concrete, from the mixer into the forms. A wooden bottom dump bucket was used to deposit the concrete under water and did the work successfully up to a depth of 17 ft.

Wages and Cost.—The gang for forms consisted of 2 carpenters and from 2 to 6 helpers and a drill boat crew setting uprights; and the gang for concreting of 14 men, including foreman, derrickman, mixerman, etc. The wages paid were as follows:

Drillmen, per month	$ 60
Foreman, per month	75
Overseer, per month	125
Carpenters, per day	2.50
Laborers, per day	$1 to $1.25

All men were subsisted in addition to regular wages, which was considered equivalent to 50 cts. per day per man additional. The prices of materials were as follows:

Coal, per ton	$ 2.20
Corrugated bars	2.85
Round bars	1.80
Cement, per bbl., f. o. b. Moline	1.14
Gravel, per cu. yd. on barge, towing extra	0.65
Lumber, per M. ft., B. M.	26.50

The cost of the work was as follows:

Item.	Total.	Per cu. yd.
Preliminary expense	$ 9,074.30	$2.0441
Supt. and office	1,798.30	0.4051
Excavation	467.50	0.1053
Totals	$11,340.10	$2.5545
Concrete work:		
Forms—		
Materials	$ 2,575.30	$0.0351
Labor	940.06	0.2117
Drilling	168.10	0.0379
Coal for drills	94.57	0.0213
Totals	$ 3,778.03	$0.8060
Concrete materials—		
Cement	$ 7,059.48	$1.5901
Cement handling	169.11	0.0381
Cement testing	130.68	0.0294
Gravel	2,847.85	0.6415
Reinforcement	104.08	0.0235
Towing	945.78	0.2131
Towing, coal for	378.28	0.0852
Totals	$11,635.26	$2.6210

Mixing and placing concrete:		
Labor	$ 2,054.60	$0.4628
Coal	283.71	0.0639
Totals	$ 2,338.31	$0.5267
Back filling	$ 203.64	$0.0459
Subsistence	1,327.32	0.2991
Plant repairs	298.66	0.0673
Totals	$ 1,829.62	$0.4123
Grand total (4,339.1 cu. yds.)	$30,721.32	$6.9205

Regarding these items it needs to be noted that the $9,074.30 for preliminary expenses includes a large number of miscellaneous items, including new machinery, erection of plant, etc., charged out in full. To compare the work with a contract job the engineer suggests taking this item at about $5,000, which represents about a 20 per cent depreciation charge on all plant used. It should be noted also that all form lumber is charged in full against this ?,178 ft. of wall, yet, as stated above, it is enough to build the remainder of the wall and should ultimately be charged against the total yardage. In the same way most of the items constituting preliminary charges must be distributed over a large yardage in addition to that of the wall already built.

The wall was built by day labor, under the direction of J. B. Bassett, M. Am. Soc. C. E., U. S. Assistant Engineer, Rock Island, Ill. We are indebted to Mr. Bassett for the data from which this analysis of costs has been prepared. The dam was a portion of the Mississippi improvement work at Moline, Ill.

Cost of Puddle.—Puddle is a mixture of gravel and clay which is wet and rammed or rolled into place. Many engineers use the clay as they would a mortar to fill the voids in the gravel. A few engineers use the gravel merely to insure the crumbling of the sides and roof of any incipient hole in the puddle so as to fill it up.

Fanning gives the following proportions measured loose:

	Cu. yd.
Coarse gravel	1.00
Fine gravel	0.35
Sand	0.15
Clay	0.20
Total loose	1.70

This when mixed, he says, will make 1.3 cu. yds., and when thoroughly rammed 1.25 cu. yds.

Another mixture given is:

	Cu. yd.
Gravel	1.00
Sand	0.35
Clay	0 25
Total	1.60

This when mixed and spread makes 1.16 cu. yds., and when rammed 1.1 cu. yd.

When clay is not available, very fine sand and a little loam can be used to fill the voids in gravel. Where puddle is used to cover

a large area, like the bottom of a reservoir, the gravel is first spread in a layer about 3 ins. thick, the clay is spread over the gravel, and the sand over the clay in their proper proportions. Then an ordinary harrow is dragged by a team back and forth until mixing is complete. Water is next sprinkled over in amount sufficient to cause the mass to knead like stiff dough under a 2½-ton rolling tamper or under a 2-ton sectional roller. Such a puddle is as heavy as concrete and resists abrasion almost as well. With labor at $1.50 and teams at $3.50, the cost is about as follows:

	Per cu. yd.
Spreading by hand	8 cts.
Harrowing	5 cts.
Sprinkling	2 cts.
Rolling	5 cts.
Total	20 cts.

An exacting engineer, however, can readily double this cost, bringing it to 40 cts. per cu. yd., which is about what it costs to spread, sprinkle and roll a cu. yd. of macadam road.

Where puddle is used in confined places, like trenches, it must be mixed like concrete and rammed to place, the cost then being 30 to 50 cts. per cu. yd. On the Erie Canal, in 1896, with wages at $1.50 for 10 hrs., the contract prices for mixing and laying puddle ranged from 20 to 60 cts. per cu. yd., the average price being 35 cts. per cu. yd., exclusive of the materials.

Cost of Sheeting and Bracing a Small Circular Reservoir.—Mr. George A. Rogers gives the following relative to the cost of sheeting and bracing a circular pit excavated for a reservoir at Kinston, N. C., in 1905:

The reservoir is 60 ft. inside diam., 20 ft. deep, and holds 15 ft. of water, or 350,000 gals. The sides and bottom are lined with brick, of which 200,000 were required. The brick side walls are 12 ins. thick at the top and 36 ins. at the bottom. The bottom lining is 6 ins. thick, being three layers of brick laid flatwise.

The first 5 ft. were excavated with drag scrapers; below that the material was a running sand which was loaded by hand into skips. The sheeting was 2 x 8 ins. x 18 ft., plank dressed on three sides. It was held by three rings (70 ft. diameter) of rangers (8 x 8-in) encircling the pit; which were held in line by 8 x 8-in. posts, 4 ft. long, spaced 5 ft. apart and bolted to the rangers. The rangers were 12 ft. long, mitered at the ends and with joints bolted.

The cost of this timber work was as follows:

10,000 ft. B. M., at $10	$100.00
Iron	30.00
6 days carpenter, at $2.50	15.00
12 days helper, at $1.00	12.00
Total	$157.00

This labor cost includes framing and assembling the rings and braces, but not the driving of the sheeting. There were about 6,000 ft. B. M. of rangers and braces, so that this framing and erecting cost $4.50 per M.

A ditch was dug all around the inside of the sheeting to lead the ground water to a sump whence it was raised by a plusometer at the rate of 450 gals. per min.

By this style of circular ring bracing, not only was very little timber required (4 ft. B. M. per cu. yd. of pit enclosed by sheeting), but the pit was left entirely open.

Cost of Dams Per Million Feet of Water Stored.—It is not unusual for hydraulic engineers to compare the cost of small reservoirs in terms of the cost per million gallons of water stored, and, in like manner, to compare large reservoirs or dams in terms of the cost per million cubic feet of water stored. The cost of small artificial reservoirs, made by throwing up banks of earth excavated from the interior, can be compared in this way with some rough degree of accuracy, but a little consideration shows how absurd it is thus to compare large reservoirs made by building a dam across a natural valley. How much water a dam will impound depends far less upon the size, and therefore upon the cost, of the dam than upon the topography of the valley above the dam. The following tabulation brings out this fact very clearly:

Dam.	Height ft.	Masonry cu. yds.	Cost.	Cost per 1,000,000 cu. ft. stored.
New Croton, N. Y......	297	833,000	$7,600,000	$1,900
Wachusett, Mass.......	207	280,000	2,000,000	238
Roosevelt, Ariz.	280	350,000	3,850,000	63
Shoshone, Wyo.........	308	69,000	1,000,000	50
Pathfinder, Wyo.......	210	53,000	1,000,000	23

Cross References on Dams and Reservoirs.—The following sections of this book contain data on dams: Earth Excavation and Embankment. Stone Masonry, Concrete Construction. Consult the index under Dams and under Reservoirs.

Waterworks Valuation and Plant Depreciation—A very complete discussion of this subject by Leonard Metcalf is given in *Engineering-Contracting*, Dec. 16 and 23, 1908, and Jan. 6 and 13, 1909. Mr. Metcalf gives also an excellent compendium of legal decisions and a very full bibliography of articles bearing upon valuations.

Figs. 29 and 30 give the depreciated value when estimated by the sinking fund formula of depreciation, for a discussion of which consult Section I, of this book. See the index under Depreciation.

Table XVI gives the life and annual contributions to the sinking fund to cover depreciation.

"Going Value" of Waterworks.—A discussion of this subject by John W. Alvord, with data and illustrative diagrams, will be found in *Engineering-Contracting*, Aug. 4, 1909.

A discussion of the subject by Chas. B Burdick is also given in *Engineering-Contracting*, Oct. 23, 1907.

Life of Cast Iron Water Pipe.—Regarding the life of cast iron water pipe, Mr. John W. Alvord says:

"It is generally conceded that cast iron pipe of hard, light-gray, close-grained iron of even texture, properly coated with good preservatives, laid in ordinary soils and conveying water of average quality, has a life that we have as yet no reliable data to determine, because a sufficient amount of it has not, as yet, lived its life, and we can only approximate what a fair average may be. The uncoated pipe first laid in England and this country about 100 years ago (1803) are every now and then taken up and exam-

TABLE XVI.

		Annual contribution to Depreciation Account or Sinking Fund in per cent of cost.	
	Useful life. Years.*	At 5% annual rate sinking fund. Per cent.	General approximate results. Per cent.
Reservoirs	50-100	0.4777-0.0383	½-0
Standpipes	25- 40	2.0952-0.8278	2 -1
Masonry buildings	40- 50	0.8278-0.4777	1 - ½
Wooden buildings	20- 50	3.0243-0.4777	3 -1
Cast-iron pipe of large diameter	50- 75	0.4777-0.1322	¾- ¼
Cast-iron pipe of small diameter	20- 40	3.0243-0.8278	3 - ¾
Steel pipe	25- 50	2.0952-0.4777	2 - ¾
Wood-stave pipe	20- 30	3.0243-1.5051	3 -2
Wrought-iron service pipe	15- 30	4.6342-1.5051	5 -2
Meters	20- 30	3.0243-1.5051	3 -2
Hydrants	40- 50	0.8278-0.4777	1 - ½
Gates	40- 50	0.8278-0.4777	1 - ½
Pumping and auxiliary machinery	20- 30	3.0243-1.5051	4 -2
Steam engines	15- 25	4.6342-2.0952	5 -3
Boilers	12- 16	6.2825-4.2270	6 -4
Electrical machinery	20- 30	3.0243-1.5051	4 -2
Average for entire plant (gravity system)			1% to ½%
Average for entire plant (pumping system)			2% to 1½%

*Except where subject to heavy deposit of silt.

ined with the result that while always found to be filled with the result of oxidation and tuberculation to a serious degree the actual body of the iron, although somewhat brittle, does not seem to have been seriously diminished in thickness."

"The coating process of Dr. Angus Smith was first introduced into this country in 1858, and by 1869 the method of coating by coal tar varnish was generally adopted, with great resulting benefit, preserving the life and carrying capacity of the cast iron pipe in a manner and to an extent which, as has been before said, is still to be determined by future observations."

Life of Pipe Wrought Iron Pipe, Lowell, Mass.—In the Proceedings of the American Water Works Association, 1894, page 181 et seq., are given some data as to the corrosion of iron and steel. An instance is cited of a wrought iron pipe, ¼ in. thick, laid at the Merrimack Co.'s Mills, Lowell, Mass., in 1845. A piece was cut

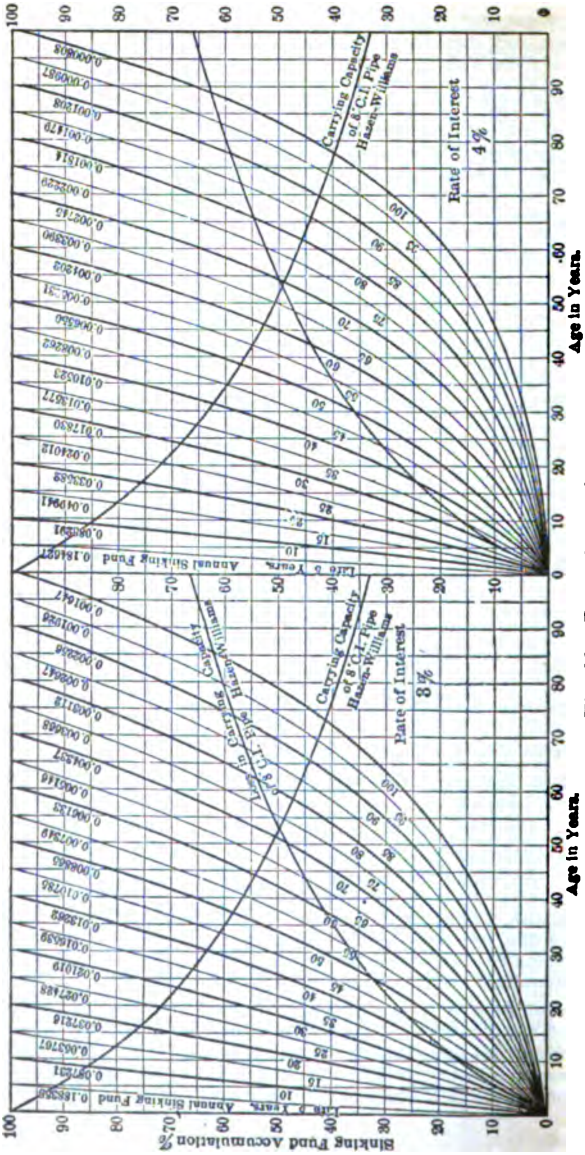


Fig. 29.—Depreciation Curves.

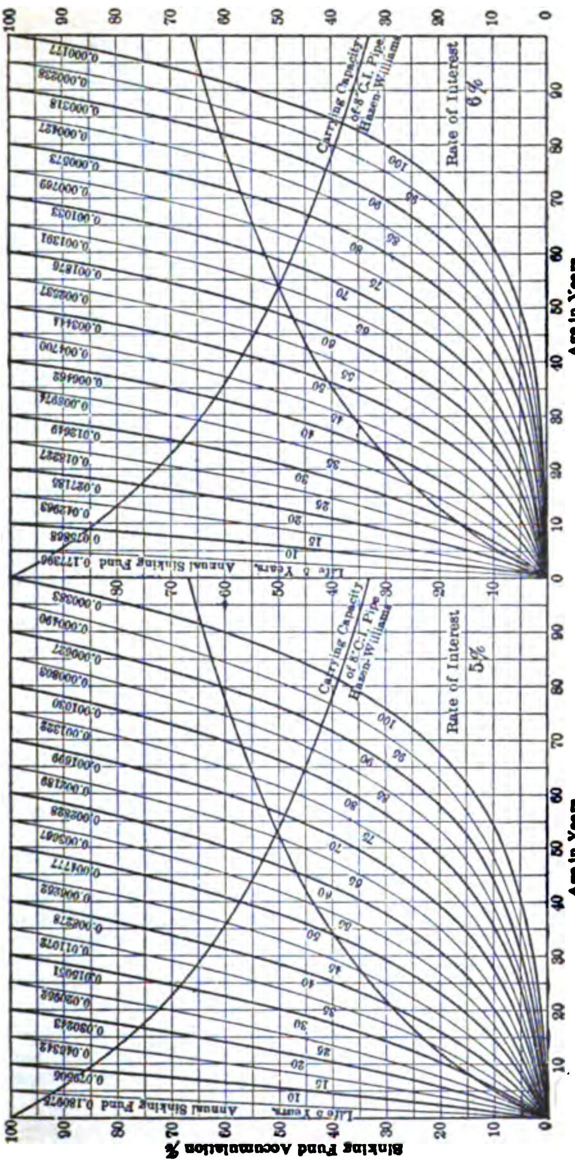


Fig. 30.—Depreciation Curves.

out in 1887, and it was evident that the pipe was good for another 40 years. The outside and inside of the pipe had originally been coated with coal tar. The conditions of soil and water were exceptionally favorable.

Life of Pipe in Salty Soil.—In the Proceedings of the American Waterworks Association, 1899, page 103, Mr. S. Tomlinson says that a 32-in. cast iron pipe, laid in an embankment across land washed by the ocean tides, was badly corroded in 10 years, and after 30 years is unfit for further use, in many places the iron being converted to oxide ½ to ¾ in. in thickness, leaving a mere shell of solid iron.

In the Proceedings of the Institution of Civil Engineers (Great Britain), Vol. 143 (1901), p. 259, Mr. William Wark says that wrought iron service pipes lasted only 7 years at Hay, whereas such pipes were still in good condition after 27 years' service at Bathhurst. The soil at Hay is of a light sandy nature, containing large quantities of salt. The soil at Bathhurst is of a rotten granite nature. Cast iron water mains at Hay show no signs of injury, but wrought iron gas mains lasted only 11 years.

Life of Pipe, St. John, N. B.—Mr. Gilbert Murdoch gave, in 1892, the following relative to the life of cast iron pipe at St. John, N. B.:

A 4-in cast iron pipe, 33 yrs. old, buried in marsh mud, burst under a pressure of 65 lbs. per sq. in. The outside of the pipe had undergone a softening at the break, which was along some air cells in the body of the shell.

A 6-in pipe, 52 yrs. old, in soft, slaty rock failed. The pipe was as easily cut as plumbago.

A 24-in. pipe, 36 yrs. old, in well drained, gravelly brick-clay, failed.

The Life of Pipe and Appraisal of Syracuse Waterworks.—Mr. Stephen E. Babcock gives the following relative to the life of cast iron pipe. In 1891, in the city of Syracuse, N. Y., condemnation proceedings were undertaken preliminary to the purchase of the waterworks owned by a private company. The engineering experts for the water company dug up sections of pipe and tested it in the presence of the court. Uncoated cast iron pipe that had been laid 40 years was found to be apparently as perfect as when first laid; it had become coated neatly and uniformly with a coating not exceeding 1/64th of an inch thick. It stood a pressure of 700 lbs. per sq. in. The water is unusually hard. Cement lined pipe (with a wrought iron core) was also dug up and tested, sizes being 4 to 10-in. It stood 300 lbs. per sq. in., and where the cement was removed the iron appeared as perfect as when laid in 1862.

The experts for the city claimed that practically no value should be assigned to existing 4 in. and 6 in. pipes, as they were too small. In rebutal it was shown that the mileage of pipes of these sizes was as follows in different cities:

	Per cent.
Syracuse, N. Y.	62
Rochester, N. Y.	70
Waltham, Mass.	81
Fitchburgh, Mass.	76
Erie, Pa.	90
Washington, D. C.	85
Schenectady, N. Y.	87
Cincinnati, O.	66
Binghamton, N. Y.	74
Port Huron, Mich.	75

As the reservoir had been built many years before, all records of the amount of excavation, etc., had been lost. The experts for the water company submitted evidence to show what similar reservoirs had cost per million gallons of storage capacity, as being the only rational means of arriving at the value of this reservoir whose capacity was known.

Estimated Depreciation of Water Pipe, Los Angeles, Calif.—In estimating the depreciation of water pipes in Los Angeles, Calif., a board of four engineers (Jas. D. Schuyler, A. L. Adams, A. H. Koebig and J. P. Lippincott) adopted the following rates of annual depreciation, for purposes of appraisal of present value:

Cast iron pipe in good soil	1.25
Cast iron pipe in poor soil	2.00
Sheet iron pipe in good soil	4.00
Sheet iron pipe in poor soil	6.77
Wrought iron pipe in good soil	3.33
Wrought iron pipe in poor soil	5.71

These depreciations were applied to the cost of the pipe in place (including pipe, lead, labor of laying, removing and replacing pavement, etc.) Soils ranging from salty shales and alkaline adobe (clay) to heavy clay were classed as "poor," and the balance as "good." After deducting the above depreciation from the first cost, a further depreciation, called internal depreciation due to tuberculation, was calculated on those depreciated values and deduced therefrom. The annual internal depreciation was estimated as follows:

	Per cent. Per year.
Cast iron pipe, 4 in. and over	0.6
Cast iron pipe, 3 in. for less than 10-yrs. of age	2.0
Cast iron pipe, 3 in. for over 10 yrs. of age	1.0
Sheet iron and steel	0.75
Wrought iron, under 4 ins., for less than 10 yrs. of age	2.00
Wrought iron, under 4 ins., for over 10 yrs. of age	1.00
Wrought iron, 4 ins.	1.50

SECTION VIII.

SEWERS, CONDUITS AND DRAINS.

General Considerations.—Trenches for sewers are usually much deeper than trenches for water pipes, because it is generally desirable to have a sewer deep enough to drain cellars and basements. In cities a common depth of trench is 8 to 11 ft. If the depth is more than about 6 ft., even in narrow trench work, men will be required on the surface to shovel the earth back from the edge of the trench after it has been cast up. In such cases always cast the earth onto plank, for reasons given in Section 2 on Earthwork. When the depth much exceeds 8 ft., it is advisable to cast the earth out of the trench in stages, using platforms about 6 ft. apart—or less if the earth is sloppy. Bear in mind that where the trench is a wide one, there is much handling of the earth after it reaches the surface, both in stacking it up in pile and in moving it back into the trench ("backfilling") after the sewer has been laid. In large sewer construction there is more excavation than backfill, and the excess must be loaded and carted away. Each case must be estimated separately, which can be done with the data given in Section 2 on Earthwork, and with the data in this section and in the previous section on Waterworks.

Deep trenching is beset with so many difficulties, such as the handling of unexpected bodies of water, the caving of banks even when well sheeted, and the like, that liberal estimates of cost should always be made. Then $7 to $10 a day should ordinarily be added for rental of a trench machine, for even where owned by the contractor a liberal allowance must be made for wear and tear and interest, since so much of the time the machine is ordinarily idle. The cost of the sheeting plank and bracing must be added, also that of pumping, if the soil is wet. In many localities glacial boulders are likely to be encountered, greatly delaying work and adding to the cost.

Accidents to men are frequent—so much so in some cities that accident insurance companies absolutely refuse to insure a sewer contractor's men. Accident insurance is seldom less than 1% of the pay roll, even on safe work, and on sewer work it often runs up to several per cent.

Cost of Sheeting at Peoria, Ill.—On a trench 13 ft. wide × 45 ft. deep, at Peoria, Ill., sheeting in 16-ft. lengths cost as follows for labor:

2 men on top, at $2	$4
2 men setting sheeting, at $2.50	5
8 men driving sheeting, at $1.50	12
8 men pulling sheeting, at $1.50	12
2 men moving lumber ahead, at $1.50	3
Total daily wages of gang	$36

This gang sheeted 12 lin. ft. of trench per day at a cost of $3 per lin. ft., all work being by hand; this is equivalent to 6⅔ cts. per lin. ft. of trench for each foot of depth. If 2-in. sheet plank were used, there were 192 ft. B. M. of sheet plank per lin. ft. of trench and probably 38 ft. B. M. of stringers and braces, say 230 ft. B. M. per lin. ft. From which we see that driving and pulling sheeting, including bracing, cost for labor about $13 per M (= 1,000 ft. B. M.) at the rate of wages above given, which is a high cost.

The cost of exactly the same kind of work, using an Adams' trench machine with steam power for driving and pulling the sheeting, was as follows:

2 timber men on top, at $2	$4.00
2 men setting, at $2.50	$5.00
1 man operating driver	2.00
2 helpers, at $1.50	3.00
1 man pulling	2.00
2 helpers, at $1.50	3.00
1 engineer	2.00
1 man moving lumber ahead	1.50
Coal, oil, steam hose and repairs	2.50
Total	$25.00

Twelve lineal feet of trench, 45 ft. deep, were timbered per day at this cost of $25, or at $2.08 per lin. ft., which is practically ⅔ the cost by hand above given, and in addition the wear of the sheet plank was less than with hand driving.

The following cost of sheeting is for hand work, trench being 12 ft. wide × 35 ft. deep:

2 timber men on top, at $2	$4.00
1 man setting	2.50
6 men driving, at $1.50	9.00
4 men pulling, at $1.50	6.00
1 man moving lumber	1.50
Total	$23.00

At this cost, 13 lin. ft. of trench were sheeted per day, or at the rate of $1.77 per lin. ft.

Smaller trenches, 8 ft. to 16 ft. deep in sand, cost from 10 to 25 cts. per lin. ft. for labor of sheeting with 2 x 7-in. hemlock. Stringers in trenches 35 ft. or more deep were 8 x 8 ins. yellow pine, with 6 x 8-in. white pine braces. In trenches of less depth 6 x 6-in. hemlock stringers and braces were used. The above costs do not include wear and tear on timber. Some sewer contractors figure on using hemlock sheeting about 4 times, with hand-driving, before it is worn out.

Cost of Pumping Water From Trenches.—The cost of pumping water from trenches is given by Mr. Eliot C. Clarke as follows for three kinds of wet trenches, namely, "slightly wet," "quite wet" and "very wet."

In a "slightly wet" trench one hand pump was used.

In a "quite wet" trench one steam pump and a line of 8-in. pipe was used, sumps or wells being 500 ft. apart; the rent of this plant is rated at $3 a day; the engineman $2.50 a day; the price of fuel is not given.

In a "very wet" trench two steam pumps and wells every 250 ft. were used; three enginemen.

The cost of pumping per lineal foot of trench was as follows:

Depth of trench, ft.	5	10	15	20	25
Slightly wet, cost per ft.	$0.06	$0.07	$0.10	$0.12	$0.18
Quite wet, cost per ft.	0.71	0.73	0.76	1.04	1.27
Very wet, cost per ft.	1.17	1.19	1.26	1.64	2.26

Cost of Trenching With Trench Excavators.—Mr. Ernest McCullough gives the following data relating to work done by the "Chicago Trench Excavator"—a machine made by the Municipal Engineering and Contracting Co.

The machine consists of an endless chain provided with cutters and scrapers which deliver the earth onto a traveling belt, the excavators and conveyors being carried by a four-wheeled traction engine, which furnishes the power. These machines are rented or sold to contractors.

In laying 7½ miles of pipe sewers at Marshfield, Wis., the daily cost of operating the machine and laying pipe was as follows:

Operator of trench digger	$ 3.00
Engineman of trench digger	2.75
Fireman of trench digger	2.25
Man trimming bottom of trench	2.25
2 men bracing trench with plank	4.00
2 pipe layers, at $2.50	5.00
2 men furnishing pipe and mortar	4.00
2 men tamping earth around pipe	4.00
1 man shoveling earth down to the tampers	2.00
2 teams and drivers scraping backfill	7.50
4 men holding the scrapers	8.00
Total labor per 10-hr. day	$44.75

About ¾-ton of coal was used daily.

The trench was 27 ins. wide and averaged 7 ft. deep. The best day's run was 850 lin. ft. of trench, or 500 cu. yds. in 10 hrs., in dry clay containing no stones. On another day nearly 500 ft. were run in spite of many stops to blast out boulders. A fair average was 400 to 500 lin. ft., or 300 cu. yds., per day. Due to the jarring of the ground by the machine it is necessary to brace the trench.

(I am informed by Mr. McCullough that records of 650 cu. yds. per day have recently been made with this machine.)

These trench excavators are made in four sizes to excavate from 14 ins. to 60 ins. in width and up to 20 ft. in depth.

As confirming these data of Mr. McCullough's, the following records given by Mr. B. Ewing are of value: In the summer of 1904, many miles of pipe sewers were built at Wheaton, Ill., by contract. Two Chicago Excavators were used, cutting a trench 2½ ft. wide, 7 to 18 ft. deep. One machine would excavate 750 lin. ft. of trench 7 ft. deep through hard clay mixed with small stones, in a 10-hr. day. In cutting trenches 15 to 18 ft., a machine would average 150 to 200 lin. ft. per day, depending upon how much bracing was necessary.

See page 651 for data on the cost of trenching with a Buckeye Traction Ditcher.

Cost of Excavating With Trench Machines.—A trench machine, as the term is here used, does not mean an earth digger, but an earth conveyor. The Carson trench machine is a good example of the type. It consists essentially of a single rail track on which a trolley travels, being hauled back and forth by the cables of a hoisting engine. The trolley carries the bucket into which the earth or rock has been loaded by hand. The single rail track is supported at intervals by a light trestle made of bents that are A-shaped.

The legs of the A-bents are provided with wheels at the bottom riding on a track straddling the trench, and the whole trestle can be moved forward in 5 to 10 mins., from time to time, as the work advances, without taking the trestle apart, unless a curve has to be rounded. These A-bents are of 6 x 8-in. spruce, 20 ft. high and have a spread of 18 ft. at the bottom. The trestle is 288 ft. long, and buckets of 1 cu. yd. each are handled. The crew and the cost of operation are the same as for a cableway.

Mr. A. W. Byrne states that in completing one 4,000-ft. section of the Metropolitan sewer system, at Boston, he used the following force:

1 engineman	$ 3.00
1 lockman	2.00
1 dumper	1.50
8 shovelers, at $1.75	14.00
2 bracers, at $2.50	5.00
2 tenders, at $2.00	4.00
4 plank drivers, at $2.00	8.00
2 men cutting down planks, at $2.00	4.00
8 men pulling planks, etc., at $1.75	14.00
Total	$55.50

The force working in a trench 9 ft. wide x 20 to 30 ft. deep averaged 64 lin. ft. a week in "boiling sand," the pressure of which would break 6 x 8-in. stringers 2½ ft. apart, and 192 ft. a week in gravel and coarse sand, which is equivalent to 70 to 110 cu. yds. a day in the running sand, and 200 cu. yds. in good ground, or at a cost ranging from 80 to 25 cts. cu. yd. A steam pump running at a cost of $10 a day was also required, and about ½-ton of coal

was used by the trench machine. The work mentioned was done after the trench machine was set up, and the gang well organized. Another contractor states that it took him two days to dismantle a machine, move it 1,000 ft. and set up again.

The Adams trench machine consists of a series of wrought-iron ∩-shaped bents, the lower feet of the ∩ being provided with wheels running on rails laid each side of the trench. These ∩ bents carried two rails, on each side, beneath the top of the bent, and a car ran along these rails; this car is pulled back and forth by cables from a hoisting engine at one end of the trench; and the same engine raises buckets up to the car where they are gripped. Working in sand at Peoria, Ill., the following was the cost in a trench 13 ft. wide x 45 ft. deep:

	Per day.
18 men loading buckets, at $1.50	$27.00
1 man operating bucket car	2.00
1 foreman	3.00
1 engineman	2.50
1 waterboy	.50
Coal, oil, etc.	1.00
Total per day	$36.00

This force excavated 284 buckets of 1 1/9 cu. yds. each, of 316 cu. yds., daily at a cost of 11.4 cts. per cu. yd., as the average of 1 month.

The same gang operating in a trench, 12 ft. wide x 33 ft. deep, averaged 288 buckets a day, at a cost of 12.5 cts. per cu. yd. Most of the excavated material was dumped directly from the buckets as backfill into the trench where the sewer was completed.

A Moore Hoister and Conveyor, which differed only in having the bucket car travel on top of the bent, instead of below, required one more man handling the buckets, making the daily force account $38. In a trench 12 ft. wide x 35 ft. deep the Moore machine daily averaged 286 buckets of 1 cu. yd. each, at a cost of 13.3 cts. per cu. yd.

These records for Adams and Moore machines show unusually low costs. They should not be taken as averages, but rather as showing the very best that can be done under favorable conditions. Mr. A. D. Thompson is my authority for these cost records. The cost of sheeting these trenches is given on pages 435 and 436.

Cost of Trench Excavation in Massachusetts, Using a Carson Machine.—Mr. H. H. Carter gives the following account of work done by contract in Massachusetts in 1884: A trench 2,100 ft. long, 9½ ft. deep and 20 ft. wide was dug for a conduit along the shore of a pond and about 30 ft. away from the water's edge. The water in the pond was 8 ft. higher than the bottom of the trench, but most of the water that entered the trench seeped in from the side farthest away from the pond. The water was handled by two Pulsometer Steam Pumps. A large quantity flowed in at some places. All water was pumped from sumps located ahead of the

laying of the brick conduit. No underdrains were left under the finished conduit. The material excavated was variable. The greater part of the conduit was built on a hard, coarse sand and gravel bottom; but for several hundred feet quicksand was encountered in the bottom. A Carson trench machine was used for 10 weeks. The total excavation was 15,100 cu. yds., or 7.2 cu. yds. per lin. ft. of trench. The backfill amounted to only 1.5 cu. yds. per lin. ft. of trench. The itemized cost was as follows for 2,100 ft., or 15,100 cu. yds.:

	Total.	Per cu. yd.
Foreman, 66 days, at $4.00	$ 264.00	$0.044
Foreman, 159 days, at $2.50	397.50	
Engineman, 123 days, at $2.50	307.50	0.020
Fireman, 147 days, at $1.75	257.25	0.016
Pumpman, 94 days, at $3.00	282.00	0.026
Pumpman, 56 days, at $1.75	98.00	
Laborer, 2,400 days, at $1.25	3,000.00	0.200
Laborer, 2,200 days, at $1.50	3,300.00	0.220
Bracer, 366 days, at $1.75	640.50	0.042
Carpenter, 7 days, at $2.00	14.00	0.001
Horse and cart, 88 days, at $4.00	352.00	0.023
Horse and cart, 10 days, at $3.15	31.50	0.002
Scraper, 71 days, at $5.00	355.00	0.024
Carson machine, 10 weeks, at $45.00	450.00	0.030
Engines, 103 days, at $2.00	206.00	0.014
Boiler, 129 days, at $1.00	129.00	0.009
Pumps (two), 199 days, at $0.80	159.20	0.011
Derricks, 72 days, at $1.00	72.00	0.005
Tools	71.00	0.005
Coal, 80 tons, at $6.00	480.00	0.032
Sheeting, loss on, at $14 per M	200.00	0.013
Iron, at 3 cts. per lb.	15.00	0.001
Miscellaneous	26.00	0.002
Total	$11,107.45	$0.740

The backfilling and embankment cost is included in the above cost of 74 cts. per cu. yd. of trench excavation. Properly it should be separated, as follows:

	Per lin. ft.
Excavating trench	$3.20
Bracing trench, labor	0.30
Bracing trench, lumber	0.10
Pumping trench	0.45
Backfilling	0.71
Embankment	0.69
Miscellaneous	0.28
Total, per lin. ft.	$5.73

Deducting the backfilling and embankment, we have left $4.33 per lin. ft., or 60 cts. per cu. yd. of trench. The backfilling itself cost 18 cts. per cu. yd. backfilled.

This same trench work was extended across a pond that had been filled with an embankment of gravel and sand from a trestle. The trench was excavated in the center of this embankment, and was 18 ft. wide, with sheet piles on both sides, and its bottom was 6 ft. below the level of the pond. The water was handled by two pulsometers and one Andrews pump. The trench was 1,550 ft. long,

containing 8,070 cu. yds. and took 125 days to excavate. The itemized cost was as follows:

	Total.	Per cu. yd
Foreman, 35 days, at $3.50	$ 122.50	$0.015
Foreman, 150 days, at $2.50	375.00	0.047
Engineman, 146 days, at $2.50	465.00	0.058
Pumpman, 286 days, at $1.75	500.50	0.062
Laborer, 400 days, at $1.65	680.00	0.085
Laborer, 460 days, at $1.50	690.00	0.086
Laborer, 2,500 days, at $1.25	3,125.00	0.383
Bracer, 255 days, at $1.75	446.25	0.056
Horse and cart, 12 days, at $3.15	37.80	0.004
Engines, 125 days, at $2.00	250.00	0.031
Boiler, 125 days, at $1.00	125.00	0.015
Pulsometers, 223 days, at $0.80	178.40	0.022
Pump (Andrews), 67 days, at $2.00	134.00	0.017
Derricks, 125 days, at $1.00	125.00	0.015
Tools	57.00	0.007
Coal, 52 tons, at $6.00	312.00	0.039
Spruce, 49 M left in, at $14.00	686.00	0.086
Miscellaneous	35.00	0.004
Total (1,550 lin. ft.)	$8,344.45	$1.032

This cost of $1.03 per cu. yd. includes some but not all of the backfilling. The cost per lin. ft. was distributed as follows:

	Per lin. ft.
Excavating	$3.25
Bracing, labor	0.29
Bracing, lumber	0.45
Pumping	0.72
Backfilling and embankment	0.66
Total	$5.37

Deducting the backfilling we have $4.71 per lin. ft., which is equivalent to 90 cts. per cu. yd. of trench. The backfilling itself cost 19 cts. per cu. yd. backfilled. The contractor's price was less than half what the work cost him, but it appears evident that he did not manage his work very well.

Cost of Excavating With a Potter Trench Machine.—The following data were published in *Engineering-Contracting*, April, 1906, and January 28, 1908. Fig. 1 shows a Potter trench machine, made by the Potter Mfg. Co., Indianapolis, Ind. The machine consists of a track supported by bents that span the trench. On this track travels a carriage having drums for hoisting the buckets of earth from the trench. The track is ordinarily 270 ft. long, the hoisting engine being located at one end. Two men ride on the carriage to handle the buckets. Buckets loaded by hand are lifted from the trench by the machine and carried back and dumped on the completed sewer for backfill.

Certain sections of an intercepting sewer were built by day labor in Chicago, during 1901-1903. A Potter trench machine 370 ft long was used. An ordinary double drum hoisting engine was placed at the front end of the machine. By means of two cables and a series of drum sheaves, the engine hoisted the bucket and moved the carrier along the trackway as required. The entire ma-

chine, including the engine, was supported on track on each side of the trench. After the track was built, 5 mins. was ample time in which to move the whole machine 48 ft., that amount of trench being worked at a time. The Potter trench machine was used to remove the clay and about 2 ft. of overlying sand.

In the excavation six ¾-yd. buckets were used, four in the trench and two on the carrier. Two empty buckets were placed in adjoining sections and two full ones removed on each trip. The trench machine crew consisted of the following: One hoisting engineman, one fireman, and two carrier men. The number of bottom men or diggers ranged from 17 to 21, depending on the

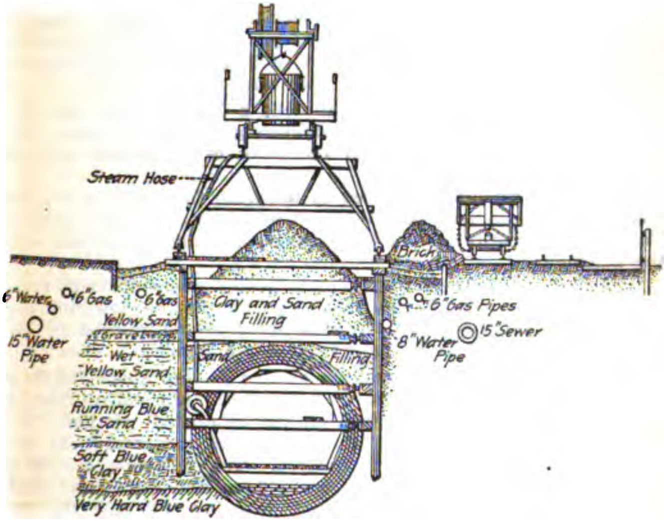


Fig. 1. Trench Machine.

kind and amount of excavation. In addition, the track supporting the machine was built by a gang of timber men, whose other duties were the removal of braces, and miscellaneous work.

The rates of wages of the trench machine crew were as follows:

	Rate.	Total.
1 foreman	$4.00	$ 4.00
2 enginemen	4.80	9.60
1 fireman	2.75	2.75
2 carrier men	3.75	7.50
17 bottom men	3.25	55.25
Total daily labor cost		$78.10

Note that the wages of laborers were very high.

One ton of coal, costing $2.90, per day was used; adding this to

the total labor cost and we get $81. About 190 cu. yds. were excavated each day, so the cost, per cu. yd., was 40.2 cts. per cu. yd., exclusive of plant rental, and cost of laying track.

During 1906, there were 2,440 lin. ft. of concrete sewer (5½ ft. diam.) built by contract for the city of South Bend, Ind.

The section of the city through which this sewer was built was flat and marshy. The material, in consequence of this, was loose black soil for a depth of about 4 ft. Then sand and gravel were encountered, and for the last 4 or 5 ft. of the trench this material was water soaked. This made pumping necessary in the excavation work and also during the progress of the concrete construction.

The trench was 10½ ft. wide, and 18 ft. was the average depth. This gave 7 cu. yds. of excavation per lin. ft. of trench. Shoring of the sides of the trench was necessary. The first 2 or 3 ft. of the trench was excavated either by men casting the material from the trench or was plowed and moved with scrapers.

After this much excavation was done a Potter trench machine, manufactured by the Potter Manufacturing Co., Indianapolis, Ind., was installed and used for all the work of excavation and for handling the concrete.

The trench machine was used to excavate from 5 to 6 cu. yds. per lin. ft., but, as no separate record was kept of the first excavation done, the entire cost of the excavation is figured as done with the machine.

It is stated that the carriage that handled the buckets could make a round trip in one minute, including the time of lowering and hoisting the buckets. The following data were furnished by Mr. W. A. Morris, Asst. City Engineer of South Bend.

On the work described it was the custom to keep about 200 ft. of the trench open at one time. The material was taken from in front of the sewer and dumped on the completed portion. The excavation on top was dry, but as it neared the bottom, as previously stated, water was encountered. The following system of drainage was used. The water came from the gravel and sand. A sub-drain pipe was laid of second class and cull pipe, the bottom of this being laid 30 ins. below the grade of the invert of the sewer. The joints were loosely caulked with tufts of sod in order to prevent the fine sand from entering the pipe. Clean gravel of medium size covered the pipe. This permitted water to enter the pipe, through which it flowed to a sump at the lower end of the new work. This sump was 18 ins. below the grade of the drain pipe, and the water was pumped from the sump by a 6-in. rotary pump over a dam into the old portion of the work.

This drained the bottom of the trench so that the concrete was readily laid, and by keeping the pump going continually, allowed the concrete to set without being injured by the water rising in the trench. This pumping and drainage work is included in the cost of excavation but a part of it could properly have been charged against the concrete work.

The wages paid for a 10-hr. day were as follows:

Engineer on trench machine	$3.00
Fireman on trench machine	1.65
Engineer for pumping	2.00
Fireman	2.50
Carpenter	2.50
Laborers	1.85

The cost of the various work per lin. ft. of trench was as follows:

Pipe for sub-drain	$0.33
Labor laying this pipe	0.35
Pumping water	0.45
Excavation and backfilling	2.80
Setting and pulling shoring	1.04
Allowance for tools and gen. ex	.25
Total per lin. ft.	$5.22

With 7 cu. yds. per lin. ft. of trench this makes a cost per cu. yd. of excavation for each of the above items as follows:

Pipe for sub-drain	$0.047
Labor laying this pipe	0.050
Pumping water	0.065
Excavation and backfilling	0.400
Shoring	0.150
Tools and general expenses	0.035
Total per cu. yd.	$0.747

The drainage, it will be noticed, cost a little more than 20 per cent of the total. The cost of excavation and back filling, and of shoring and filling the street piles for a trench as deep as this is quite reasonable.

Cost of Excavating With Potter Trenching Machine for 16-ft. Sewer.*—The final section of the conduit work proper for the Lawrence avenue sewer at Chicago, Ill., includes the construction of 1,160 lin. ft. of 5-ring, 16 ft. diameter brick conduit from the north branch of the Chicago river to the section completed in 1901 by Farley & Green. The sewer will empty in the north branch, which is being dredged to a width of 90 ft. ultimately this width will be increased to 180 ft.

The excavation was done by the open cut method, the width of the trench being 21 ft. and the average depth being 30.5 ft. The materials encountered in the excavation consist of a top layer of black soil, then come about 15 ft. of soft blue clay, 6 to 8 ft. of stiff blue clay, 1 ft. of sandy loam and about 2 ft. of hard blue clay. This latter was so hard in places that its removal was facilitated by "shooting."

The first 16 to 18 ft. of excavation was done with the aid of skips and a derrick of the Kearnes type, having a 55-ft. boom and equipped with a 7 x 10 double drum hoisting engine. The derrick is so arranged that the boom can swing in a half circle on either side of the trench. The framework carrying the turntables spanning the trench rests on shoe timbers, these in turn resting on rollers. A runway is built ahead of these rollers, and the derrick

**Engineering-Contracting,* Oct. 9, 1907.

is pulled ahead by means of ropes wound round the nigger head of the engine and single and double blocks. The skips are of 1 cu. yd. capacity, were filled by hand shoveling, lifted by the derrick and swung to one side of the trench, the spoil being used for filling low places, or later for completing the backfilling. As the excavation proceeds, a 2-in. plank sheeting is placed and carried down to a depth of about 14 ft., 8 x 10-in. timber spaced 20 ft. centers being used for bracing.

A Potter trenching machine followed the derrick and skips, and was used in carrying down the excavation to the required depth. Six ½ cu. yd. capacity buckets are used with this machine, there always being four buckets in the trench being filled, while the remainder are being carried back on the carriage and dumped on the completed brick work. The hardest part of the excavation was done with this machine, the clay being sticky and tenacious and coming away in hard lumps. An average of 175 to 200 cu. yds. was excavated each day with this machine.

The wages per 8-hour day and number of men employed in excavating with the Potter trenching machine were about as follows:

	Per day.	Total.
Engineer	$6.00	$ 6.00
Fireman	2.50	2.50
1 man on carriage	2.50	2.50
1 man on carriage	3.25	3.25
20 bottom men	2.75	55.00
1 man on dump	2.75	2.75
Foreman	3.50	3.50
Total		$75.50

One-half ton of coal was consumed each day by the machine, allowing $2.50 for this and assuming that the rent of the machine was $125 per month ($4.80 per day) the total cost per 8-hour day would be $82.80. On the basis that 175 cu. yds. of material was excavated each day, the cost would be about 47 cts. per cubic yard.

The bricklayers follow the trenching machine, six masons working to a shift. About 1,700 brick were used per foot of sewer, the average rate of progress being 16 ft. of sewer completed per day. This means that one bricklayer puts in place 4,500 brick per day, at a cost for his labor, in the wages at $6 per 8 hours, of $1.33 per thousand of brick, or about $2.65 per cubic yard of masonry. This, of course, does not include bricklayers' helpers, cost of materials or centers.

The work, which was completed recently, was done by the American Engineering & Construction Co. of Chicago, of which Mr. W. A. Shaw is president.

Cost of Excavating With Trench Machine.—In *Engineering Contracting*, April, 1906, the method of excavating a sewer in Chicago with a Potter trench machine is illustrated and described. The machine was 370 ft. long, and was moved forward 48 ft. at a time, only 5 minutes being required to make a move. The crew ·gging and operating the machine was:

		Per day.
1	foreman	$ 4.00
2	enginemen at $4.80	9.60
1	fireman	2.75
2	carrier men at $3.75	7.50
17	bottom men at $3.25	55.25
	Total labor	$78.10
1	ton coal	2.90
	Total, 190 cu. yds. at 40.2 cts.	$81.00

Note that the laborers were paid very high wages. They were working for the city.

Cost of Trenching by Cableways.—A cableway consists essentially of a main cable suspended between two towers, and serving as a track for the trolley carrying the loaded bucket, which is pulled back and forth by small cables from a stationary hoisting engine. The following data will give a good idea of what can be done with a cableway.

Parallel with a railroad track a trench 14 ft. wide by 18 ft. deep was dug in earth slightly more compact than "average." A Lambert cableway with towers 400 ft. apart was used, and it delivered the buckets to a chute that discharged into railroad cars alongside. The writer's record of cost was as follows:

		Per day.
30	men loading buckets, at $1.50	$45.00
1	signalman (signaling engineman), at $1.75	1.75
1	man hooking buckets to cable's trolley, at $1.75	1.75
1	man dumping buckets, at $1.75	1.75
4	men driving sheet plank and bracing, at $1.50	6.00
5	men spreading earth in cars and moving cars, at $1.50	7.50
1	engineman	3.00
1	fireman	1.75
1	waterboy	1.00
1	foreman	4.00
	Total	$73.50

The output was 260 buckets in 10 hrs., each bucket holding 1⅓ cu. yds. of loose earth, which was probably not much more than 1 cu. yd. measured in cut. The wages and coal amounted to $76 a day. Hence, not including the cost of timber sheeting, nor the hauling and unloading of cars, the cost of excavation was about 30 cts. per cu. yd. There was no backfilling, as the trench was for a retaining wall. When the bucket was traveling 360 ft. from pit to dump, the following time was required for each round trip:

	Seconds.
Raising bucket	15
Moving bucket 360 ft.	35
Dumping bucket	25
Returning bucket	35
Lowering bucket	15
Changing buckets	15
Total	140

Almost 5 secs. could be saved on each of these six items if everything went well, but with the ordinary slight delays the above is a fair average for each round trip—that is 2⅓ mins. A cableway may be used to advantage in pulling sheet planking, and one 2 x 10-in. plank buried 16 ft. in the earth can be pulled in 1 min., thus making the cost of timber removal merely nominal. In pulling the plank use a piece of 1 x 3-in. iron bent into a U-shape and with a ring welded to one leg of the U. It clings to the plank even though it is not held by a set screw or the like.

To move one of these cableways takes a gang of 15 men three days if they are "green" at the work, two days if they are used to it. The anchorage for the main cable is made by digging a trench 5 or 6 ft. deep and 16 ft. long, in which a log 16 or 18 ins. in diameter and 15 ft. long is laid, and the cable carried around its center. A short narrow trench leads off from the main trench so as to give a clear way for the cable to pass to the top of the tower. The main trench is filled with stones carefully laid over the log, and on top of the ground over the log is built a pile of stones 6 ft. high x 12 x 12 ft. To move all this rock for the anchors, to move the engine, towers, cables, etc., and set up again will seldom cost less than $50, and frequently costs $75, to say nothing of the lost time. If this cost is added to the cost of excavating the earth in a trench 370 ft. long, it will amount to several cents per cu. yd. Thus if the trench is only 6 ft. wide x 9 ft. deep, there will be 740 cu. yds. in 370 ft. of trench, and if it costs $74 to move the cableway, we have 10 cents per cu. yd. of trenching chargeable to the cableway moving, besides the cost of excavation and backfill. For deeper and wider trenches this cost of moving, being distributed over a greater yardage, becomes a comparatively small item. Each case must be treated as a separate problem, in ascertaining the cost.

The following data have been obtained from The Carson Trench Machine Co., of Charlestown, Boston, Mass., makers of the Carson-Lidgerwood cableway much used on the Rapid Transit Subway New York City:

Two A-shaped bents or towers, 20 to 35 ft. high, and 200 to 300 ft. apart, support the 1½-in. cable along which the bucket travels. A hoisting engine at one end with two 7 x 10-in. cylinders and capable of lifting 5,000 lbs., raises and transports the buckets at a speed of 440 ft. a minute, or 5 miles an hour.

Aside from the men required to fill the buckets, the force required consists of an engineman, a fireman, a signalman, and a dumpman; and ⅓ to ½-ton of coal is daily consumed. On a sewer in Orange, N. J., 44 buckets (1 cu. yd.) were handled per hour on an average, 60 being the maximum. The output depends upon the number of men digging, and the character of the material, but 250 cu. yds. a day may be taken as a good output.

The following costs are given in letters to the Carson Trench Machine Co.

Mr. Frank P. Davis, C. E., gives the following for a sewer in Washington, D. C.: Width of trench, 18 ft.; depth at which cableway began work, 15 ft.; distance of travel of 1 cu. yd. bucket, 150 ft.; number of trips per hour, 35; hours per day, 8; material, cemented gravel. Cost:

Engineman	$ 2.00
Fireman	1.25
Signalman	1.00
2 dumpers, at $1	2.00
Coal, oil and waste	1.50
Interest and maintenance (estimated)	7.00
	$14.75
30 men picking and shoveling	30.00
Total for 280 cu. yds	$44.75

Cost of picking, shoveling, hoisting 15 ft. and conveying 150 ft. to wagons, 16 cts. cu. yd. (Note that the wages were very low.) Bracing and sheeting was going on at the same time; the men did not know they were being timed.

James Pilkington, of New York, says: "I have excavated and refilled 250 cu. yds. in 10 hours at an expense of 15 cts. per yard. For rock excavation the cableway has no equal. I have taken the machine down and moved 250 ft., and put up, and was in working order in three hours and fifty minutes." This is unusually fast and indicates that Mr. Pilkington did not raise his towers by "main force and awkwardness."

Cost of Sewer Trench and Back Filling.—The city of Holyoke, Mass., built a system of sewers during 1908. The main sewers are 39 ins. and 54 ins. These are built of concrete blocks, there being 1,233 lin. ft. of them. The sewers were built by contract, but the excavation and backfilling was done by day labor, under the direction of the city engineer.

One trench was dug 14 ft. deep and about 4½ ft. wide, through sand and clay. The material was thrown on the side of the trench and used for backfilling. The following wages were paid for an 8-hr. day:

Foreman	$3.50
Laborers	2.00

There were excavated from this trench 2⅓ cu. yds. per lin. ft. The cost per cu. yd. was $1.21, giving a cost per lin. ft. of $2.82.

The second trench was 14 ft. deep and about 6 ft. wide, the material being the same, mainly sand and clay. There were 3.11 cu. yds. of excavation per lin. ft. The cost of excavating and backfilling this trench was $1.25 per cu. yd., making a cost per lin. ft. of $3.90. All the excavation and backfilling was done by hand.

These high costs show how inefficient is the day laborer when working in the employ of a city instead of a contractor.

Cost of Excavating Trench With Orange Peel Bucket.—In *Engineering-Contracting,* April, 1906, a detailed description is given of the plant and methods used in building a large sewer in Chicago by city forces. For part of the work a 1 cu. yd. orange peel bucket was used. A traveling derrick, on rollers, was used. It was designed to swing in a full circle. The crew was:

	Per day.
1 engineman	$ 4.80
1 fireman	2.50
1 signal man	3.25
1 powder man	3.25
2 laborers at $3.25	6.50
Total per day	$20.30

Under ordinary conditions, the orange-peel bucket excavated about 450 cu. yds. a day, all earth being dumped on a spoil bank at one side.

On the assumption that 450 cu. yds. were excavated per day, the labor cost was 4.5 cts. per cu. yd. About 50 lbs. of dynamite and ¾ ton of coal were used each eight-hour day. The cost of the dynamite was $7.50 and the coal cost $3 per ton, making the total cost for dynamite and coal $9.75. The total cost per day for excavating thus was $30.05; and the cost per cubic yard was 6.6 cts., exclusive of the wear and tear on the machine.

In this excavation the swinging derrick with the orange-peel bucket could be worked to better advantage than a steam shovel, inasmuch as it could work between the braces, which were 11 ft. centers. The bracing was placed as the excavation proceeded, and when the trench excavation was completed, the braces were all in place. By the use of the derrick the excavated material could be deposited far enough from the trench so as not to necessitate rehandling. In the case of a steam shovel it would have been necessary first to put in a temporary bracing, and a permanent bracing afterwards. Also, the boom of a steam shovel would not be long enough to deposit the excavated matter the necessary distance from the trench.

Cost of Sewer Trenching Using a Derrick.*—The trenching was done for a trunk sewer constructed at Big Rapids, Mich. The trench was 4 ft. wide and varied from 14 ft. 2 ins. to 17 ft. 3 ins. deep. A 15-in. pipe sewer was laid in the trench. A length of 1,000 ft. of sewer was constructed. The material was gravel and boulders. As much as 3 cords of stone in 400 ft. of trench were removed, many of the boulders required a 3,000-lb. chain fall to handle them. In addition most of the stone lay from 12 to 16 ft. deep, which made it very difficult to handle them between the braces. The gravel was treacherous and hard to hold, requiring two and sometimes three sections of sheeting and three and four stringers to hold it.

**Engineering-Contracting,* Sept. 8, 1909.

The first 4 to 6 ft. of the trench was excavated by means of a slush scraper fitted with inside ears and bail so that it would cut vertical sides without the use of shovel or pick. A team and driver at $3.75 per day did all this digging and also all filling. The gang employed and the wages per day were as follows:

Item.	Per day.
1 foreman at $2	$ 2.00
1 scraper team and driver at $3.75	3.75
1 man holding scraper at $1.50	1.50
1 man dumping scraper at $1.50	1.50
2 men pulling sheeting and carrying it ahead at $1.50	3.00
1 man setting top section of sheeting at $1.50	1.50
1 man tending derrick at $1.50	1.50
1 horse and driver on haul line at $2.50	2.50
4 men filling 2 buckets at $1.50	6.00
1 man laying pipe at $2	2.00
1 pipelayer's helper at $1.50	1.50
Total	$26.75

This gang completed from 46 to 54 ft. of sewer per day; this gives a labor cost of 58.2 cts. to 49.5 cts. per lin. ft. of sewer.

The derrick used on this work was a No. 1 Parker derrick made by the Parker Hoist & Machine Co., Chicago, Ill. Regarding the service of this derrick the contractor, Mr. D. J. Shafer, Big Rapids, Mich., says:

"In speaking of the derrick I can say that it reduced the cost of my ditch from 78 cts. per lin. ft. to 59 cts. per lin. ft. As soon as I put the derrick on the job I cut my crew from 26 and 28 men down to 16 men and dug more trench with much more ease than I did with the 28 men. The buckets held about 1/6 cu. yd. and with common work and 4 men filling buckets, 1 man dumping buckets, 1 man on the machine, with 1 man and horse, would handle 61 to 68 buckets of dirt every hour for 10 hours each day. In regard to moving the derrick, will say it never took us over 7 mins. to pull up stakes, move ahead 16 to 32 ft. and stake down and ready to lift dirt from the ditch. We moved the derrick two and three times a day."

Sizes and Prices of Sewer Pipe.—The manufacturers of vitrified sewer pipe east of the Illinois-Indiana line adopted, December 19, 1901, the standard weights and list prices given in Tables I, II and III. The western manufacturers use weights and list prices shown in Table IV.

On the Pacific Coast and in parts of the Northwest and Southwest some strictly local lists are used occasionally.

The standard length is 2 ft. for pipes up to and including 24-in. pipe. The standard length is 2½ ft. for 27-in. to 36-in. pipe. The size of the pipe is designated by its inside diameter. It will be noted that the list prices vary almost exactly with the weight of the pipe. Up to 18 diam. the Western price list follows closely the formula: List price $= 0.4d^2 + 15$.

TABLE I.—PRICES AND WEIGHTS OF STANDARD SEWER PIPE.

Size, inches.	2 & 3.	4.	5.	6.	8.	9.
Straight pipe, per foot.....	$0.16	$0.20	$0.25	$0.30	$0.50	$0.60
Elbows and curves, each..	0.50	0.65	0.85	1.10	2.00	2.40
Ys and Ts, inlets smaller than 15 ins., each......	0.72	0.90	1.13	1.35	2.25	2.70
Traps, each	1.50	2.00	2.50	3.50	6.50	7.50
Weight, per ft., lbs.........	7	9	12	15	23	28

Size, inches.	10.	12.	15.	18.	20.	21.
Straight pipe, per foot....	$0.75	$1.00	$1.35	$1.70	$2.25	$2.50
Elbows and curves, each..	3.00	4.00	5.40	6.80	9.00	10.00
Ys or Ts, inlets smaller than 15 ins., each......	3.40	4.50	6.10	7.65	10.13	11.25
Traps, each	9.00	15.00	22.00	....	....	....
Weight, per ft., lbs........	35	43	60	85	100	120

Size, inches.	22.	24.	27.	30.	33.	36.
Straight pipe, per foot.....	$2.75	$3.25	$4.25	$5.50	$6.25	$7.00
Elbows and curves, each..	11.00	13.00	20.00	27.50	30.00	32.50
Ys or Ts, inlets smaller than 15 ins., each........	12.38	14.63	21.25	27.50	31.25	35.00
Weight, per ft., lbs.........	130	140	224	252	310	350

TABLE II.—DIMENSIONS OF SEWER PIPE.

Standard Pipe.

Size of Pipe. in.	Thickness. in.	Depth of Socket. in.	Cement Space. in.	Weight per ft. lbs.
2	7/16	1½	¼	6
3	½	1½	¼	7
4	½	1⅝	⅜	9
5	⅝	1¾	⅜	12
6	⅝	1⅞	⅜	15
8	¾	2	⅜	23
9	13/16	2	⅜	28
10	⅞	2⅛	⅜	33
12	1	2¼	½	45
15	1⅛	2½	½	65
18	1¼	2¾	½	75
20	1⅜	3	½	95
21	1½	3	½	110
22	1⅝	3	½	125
24	1¾	3¼	½	145

Special Deep Socket Pipe.

Size of Pipe. in.	Thickness. in.	Depth of Socket. in.	Cement Space. in.	Weight per ft. lbs.
4	½	2	½	10
5	⅝	2½	⅝	13
6	¾	2½	⅝	17
8	¾	2¾	⅝	25
10	⅞	2¾	⅝	35
12	1	3	⅝	48
15	1⅛	3	⅝	70
18	1¼	3¼	⅝	80
20	1⅜	3½	⅝	100
24	1¾	4	⅝	150

Table III.—Dimensions of Double Strength Sewer Pipe.
Standard Socket.

Size of Pipe. in.	Thickness. in.	Depth of Socket. in.	Cement Space. in.	Weight per ft. lbs.
15	1¼	2¼	½	80
18	1½	2½	½	100
20	1⅔	2¾	½	125
21	1¾	3	½	138
22	1⅞	3	½	155
24	2	3¼	½	200
27	2¼	4	¾	260
30	2½	4	¾	300
33	2⅝	5	1¼	340
36	2¾	5	1¼	380

Table IV.—Western Price List of Standard Vitrified Pipe.

Inside Diameter, ins.	Straight Pipe, per ft.	Curves and Elbows, each.	T and Y Branches, 2 ft. long, each.	*Traps, each.	†Double Branches and Breeches, each.	Increasers, Decreasers, and slants, each.	Depth of Socket, ins.	Weight per ft., lbs.	Carloads, 14 tons, ft.
3	$0.15	$0.50	$0.60	$1.70	$0.90	$0.45	1½	6	4,650
4	.20	.60	.80	2.10	1.20	.60	1⅝	10	2,800
5	.25	.75	1.00	2.50	1.50	.75	1⅝	12	2,330
6	.30	1.00	1.20	2.90	1.80	.90	1⅞	16	1,750
7	.35	1.25	1.40	3.50	2.10	1.05	1⅝	18	1,550
8	.45	1.65	1.80	4.50	2.70	1.35	2½	24	1,100
9	.50	1.75	2.00	5.00	3.00	1.50	2½	27	1,040
10	.60	2.10	2.40	6.00	3.60	1.80	2½	30	930
12	.75	2.75	3.00	8.50	4.50	2.25	3	40	700
15	1.00	3.75	4.00	....	....	3.00	3⅛	60	470
18	1.50	4.75	6.00	....	....	4.50	3¼	85	330
20	1.75	5.75	7.00	....	....	5.25	4	105	270
21	2.00	6.75	8.00	....	....	6.00	4	110	260
24	2.50	8.00	10.00	....	....	7.50	4	135	210
27	3.25	16.25	16.25	....	....	16.25	4½	215	129
30	4.00	20.00	20.00	....	....	20.00	4⅛	270	108
33	5.00	25.00	25.00	....	....	25.00	5	320	90
36	6.00	30.00	30.00	....	....	30.00	5¼	365	81

Sizes 3-in. to 6-in., inclusive, in 2-ft. lengths.
Sizes 8-in. to 18-in., inclusive, in 2½-ft. lengths.
Sizes 27-in. to 36-in., inclusive, in 3-ft. lengths.
*Both P Traps and Running Traps are made with or without hand holes.
†Double Branches, both T and Y above 12-in. made only to order.
Branches, Increasers, Decreasers, Slants, 27 to 36-in. are 3 ft. long.

Large discounts from these prices are given. The present (August, 1909) discount for Eastern Pennsylvania is as follows:

	Per cent off.
Standard Pipe—	
3-in. to 24-in., inc.	79
27-in. and 30-in.	71
33-in. and 36-in.	66
Double Strength—	
15-in.	74
18-in.	73
20-in. to 24-in.	72
27-in. and 30-in.	63
33-in. and 36-in.	58

No. 2 Pipe—	
3-in. to 24-in., inc.	81
27-in. and 30-in.	76
33-in. and 36-in.	71

All pipe and branches in 2½ ft. or 3 ft. lengths to take 2 per cent less discount than above, except 27 in. and over.

Deep and Wide Sockets on Standard Pipe 4-in. to 24-in., inclusive, 2 per cent less than schedule discount. No extra charge is made for Deep and Wide Sockets on Double Strength Pipe 15-in. to 24-in. inclusive. Sizes 27-in. to 36-in., inclusive, are made only in Deep and Wide and no extra charge is made for same.

On First Quality Pipe, 1 per cent less discount than the above for allowing breakage and inspection at railroad point of delivery.

Freight allowed on car lots to points where the rate on Sewer Pipe from Akron, Ohio, is more than 14 cts. and does not exceed 16 cts. per cwt.

Terms: 30 days or 2 per cent off net bills, after all deductions have been made, for cash in 15 days from date of shipment. Breakage (if any) in transit, at risk of purchaser. (Patton Clay Mfg. Co., Patton, Pa.)

Discounts from Western List, St. Louis, delivery (Evens & Howard Fire Brick Co., St. Louis), August, 1909, are:

Standard Pipe—	Per-cent.
3-in to 6-in.	77½
8-in. to 12-in.	75
15-in. and 18-in.	70
20-in. to 24-in.	65
27-in. to 30-in.	62½
33-in. to 36-in.	60
Double Strength—	
12-in.	70
15-in. and 18-in.	65
20-in. to 24-in.	60
27-in. and 30-in.	57½
33-in. to 36-in.	55

Cement Required for Sewer Pipe Joints.—There are two kinds of sewer pipe: (1) The standard pipe with shallow joints; and (2) the special deep-socket pipe with wide and deep joints. The dimensions of these two kinds of joints are given in Tables II and III. Unless otherwise specified, the standard pipe with shallow joints is used; but many engineers prefer the deep-socket pipe, and specify it.

If the mortar is filled in the pipe joint and cut off vertically, flush with the face of the bell, the joint is called a "flush joint." If the mortar is also plastered on the outside, and beveled on a 1 to 1 slope from the outer edge of the bell to the body of the entering pipe, the joint is called an "overfilled joint" or a "beveled joint." The amount of mortar required for each of these kinds of joints is given in Tables V and VI. I have made no allowance for the space in the joint occupied by gasket or yarn. For discussion of the amount of cement per cubic yard of mortar see page 253.

TABLE V.—CEMENT REQUIRED TO LAY 100 FT. OF STANDARD SEWER PIPE.

(2-ft. Lengths.)

Size of pipe, ins....	4.	6.	8.	10.	12.	15.	18.	20.	24.
Cu. yds. mortar:*									
Flush joints.....	.009	.013	.014	.018	.025	.040	.050	.055	.065
Overfilled joints..	.020	.036	.058	.072	.087	.116	.160	.260	.310
Bbls. cement (1 to 1 mortar):									
Flush joints.....	.036	.052	.056	.072	.100	.160	.200	.220	.260
Overfilled joints..	.080	.144	.232	.288	.348	.464	.640	1.04	1.24
Bbls. cement (1 to 2 mortar):									
Flush joints.....	.027	.039	.042	.054	.075	.120	.150	.165	.195
Overfilled joints..	.060	.108	.174	.216	.261	.348	.480	.780	.930

TABLE VI.—CEMENT REQUIRED TO LAY 100 FT. OF SPECIAL DEEP SOCKET PIPE.

(2-ft. Lengths.)

Size of pipe, ins....	4.	6.	8.	10.	12.	15.	18.	20.	24.
Cu. yds. mortar:*									
Flush joints.....	.035	.050	.060	.075	.090	.130	.145	.170	.260
Overfilled joints..	.065	.100	.140	.170	.200	.300	.340	.440	.600
Bbls. cement (1 to 1 mortar):									
Flush joints.....	.140	.200	.240	.300	.360	.520	.580	.680	1.04
Overfilled joints..	.260	.400	.560	.680	.800	1.20	1.36	1.76	2.40
Bbls. cement (1 to 2 mortar):									
Flush joints.....	.105	.150	.180	.225	.270	.390	.435	.510	.780
Overfilled joints..	.195	.300	.420	.510	.600	.900	1.02	1.32	1.80

*The number of barrels of cement required to make 1 cu. yd. of mortar is given on page 253. I have assumed 4 bbls. per cu. yd. for 1 to 1 mortar, and 3 bbls. per cu. yd. for 1 to 2 mortar.

To calculate the cost of cement per lineal foot of pipe line multiply the fraction of a barrel of cement (given in Tables V and VI) by the prices of cement in dollars per barrel. Thus, if cement is $2 per bbl., and the mortar is mixed 1 part cement to 1 part sand, and deep-socket pipe is to be used with overfilled joints, we find, from Table VI, that a 6-in. pipe requires 0.4 bbl. cement, multiplying this 0.4 by 2, gives 0.8 ct. per lin. ft. as the cost of cement, when cement is $2 per bbl. Under these same conditions the cost of cement per lin. ft., for different sizes of pipe, is as follows:

Size of pipe, ins........	4	6	8	10	12	15	18	20	24
Cement, per ft., cts.....	0.5	0.8	1.1	1.4	1.6	2.4	2.7	3.5	4.8

Cost of Hauling Sewer Pipe.—The weight of sewer pipe is given in Table I, and if 2 tons (4,000 lbs.) are hauled per wagon load, a wagon will carry the following amounts of pipe at the costs given:

Size of pipe, ins....	4	6	8	10	12	15	18	20	24
Lin. ft. per wagon..	444	26[illegible]	174	114	92	66	46	40	28
Cost of hauling, cts. per lin. ft., per mile	0.10	0.15	0.25	0.40	0.5	0.7	1.0	1.1	1.6

The cost of hauling is based upon wages of $3.50 a day for team and driver, and 16 miles traveled per day. It is assumed that enough men are provided at both ends of the haul to load and unload the wagon rapidly enough to leave the team time to cover its 16 miles, or that extra wagons are provided for each team. The

cost of hauling 12-in. pipe, it will be seen, is ½-ct. per lin. ft. per mile. This does not include the cost of loading and unloading the pipe, which is practically as much more as the cost of hauling it one mile. Thus for 12-in. pipe, the cost of loading and unloading is ½-ct. per lin. ft., and to this must be added the cost of hauling at the rate of ½-ct. per lin. ft. per mile of distance from the freight yard to the sewer. In other words, to calculate the cost of loading and hauling pipe, determine the actual number of miles from the freight yard to the sewer and add 1 mile (to cover the cost of loading and unloading), then multiply by the cost of hauling given in the table. For example, if the actual haul is 1½ miles, then, by the rule, add 1 mile, which makes 2½ miles. If the pipe is 10-in. pipe, the table gives us 0.4 ct. per ft. per mile, which multiplied by the 2½ miles gives 1 ct. per ft.

Cost of Laying Sewer Pipe.—This will depend largely upon whether each pipe layer is provided with one or with two helpers to mix mortar and supply materials. As will be seen from cases subsequently given, two helpers to each pipe layer do not ordinarily increase the output sufficiently to justify the extra cost.

Pipe laid in a trench dug in rock, or in quicksand, usually costs twice as much for the labor of laying as in ordinary earth. When a pipe layer receives $2.25 and his helper receives $1.75 a day, the following costs per lineal foot are easily attainable under good management, and where no rock or quicksand are encountered:

Size of pipe, ins......	4	6	8	10	12	18	20	24	30	36
Cts. per lin. ft........	1	1¾	2	2½	3	3½	4	4½	5	6

As will be seen from records given later on, the costs of pipe laying are frequently two or three times the above figures, but any contractor who finds his costs running higher than the above, had better investigate his management. By giving the men a bonus for every foot laid in excess of a given number of feet laid each day the costs of pipe laying may be reduced considerably below the above given figures. Of course the cost of trenching and backfilling is not included in the above costs.

Diagram Giving Contract Prices of Sewers.—The diagram, Fig. 2, is one that I have prepared from data given by Mr. G. M. Warren, based upon contract prices for about 60 miles of sewer work in Newton, Mass., and covering a period of four years, 1891-1895. The wages of common laborers were $1.50 for 10 hrs.

The prices for trenching include excavating, sheeting and backfilling in earth; and do not relate to work in rock or quicksand.

The price of 1 ct. per inch of diameter of pipe per lin. ft. laid, includes hauling of pipe, labor of laying, and cement for joints.

The price of pipe is 70% off the list price given in Table I, plus 20% to cover the cost of branches which are placed 25 ft. apart. For example, the list price of 12-in. pipe is $1.00; and with 70% discount the price becomes 30 cts. Now, 20% of 30 cts. is 6 cts., which approximately covers the extra cost of branches spaced 25 ft. apart, so that the total cost of the pipe for a 12-in. pipe line is 30 cts. plus 6 cts., or 36 cts. To this is added 12 cts. (1 ct. for

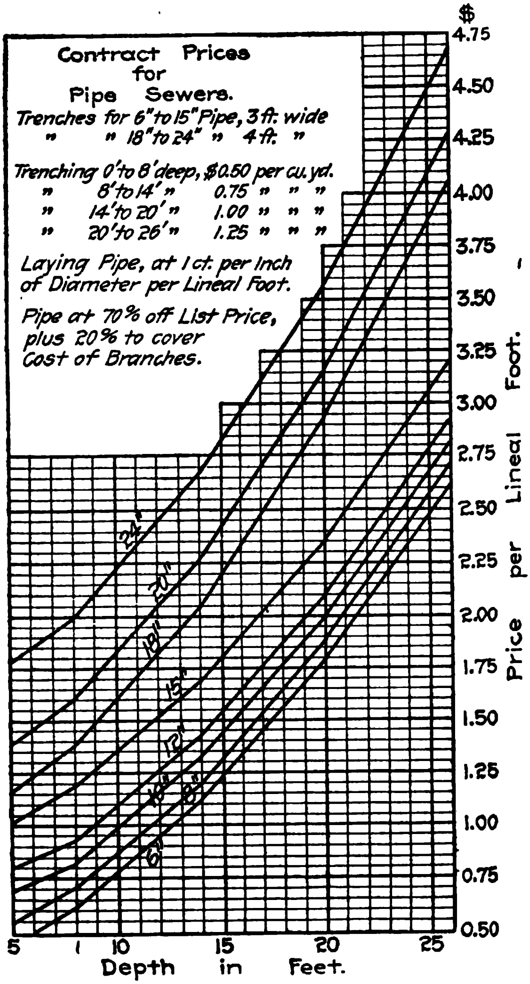


Fig. 2. Contract Prices of Pipe Sewers.

each 12 ins. of diameter) to cover the price af "laying," making a total of 48 cts., exclusive of trenching. The first 8 ft. in depth of trench are dug at a price of 50 cts. per cu. yd. The next 6 ft. below are dug at a price of 50 cts. per cu. yd., and the price for each succeeding 6-ft. lift is 25 cts. higher per cu. yd. than the preceding lift. This is based upon the assumption that trench machines are not used, and that the earth is raised in 6-ft. lifts.

To show how to use the diagram, an example will serve. Suppose it is desired to know the contract price for a 12-in. sewer in a trench 15 ft. deep. Start at the bottom of the diagram on the line marked *15*, and follow the line up until it meets the sloping line marked *12"*. Then starting from this intersection, follow the straight line across the page to the right until the side of the diagram is reached, when it will be seen that the intersection is just one division above $1.50; and, as each division is equal. to 5 cts., the price is $1.55 for a 12-in. pipe in a 15-ft. trench. This price includes contractor's profits.

Cost of Pipe Sewers at Atlantic, Ia —In *Engineering-Contracting*, May 15, 1907, appeared the first of a series of articles on the cost of pipe sewers, the data for which were gathered by Mr. M. A. Hall, the engineer in charge of the work. Mr. Hall had the inspectors report daily the organization of the forces working under the various contractors, and the amount of work accomplished. With the exception of the item of cement used in filling the pipe joints, it is believed that these records of cost are very reliable. The first of this series of articles related to sewer work at Atlantic, Iowa. The data, as originally published in *Engineering-Contracting*, were so voluminous that I have made a great condensation, but I believe that, in the condensed form here given, the costs are more available for use, and that nothing of great importance has been omitted.

The excavation was, for the most part, a clay not difficult to spade, and requiring little or no bracing and practically no pumping. The "bottom men" shoveled the earth out of the trench and the "top men" shoveled as much of it back from the edge as was necessary. The backfilling was done, for the most part, by a team and drag scraper, and there was no ramming.

Table VII gives the costs at Atlantic, Ia. To the labor costs. Mr. Hall thinks 10% should be added for overhead charges and incidentals, to cover office expenses, hauling tools, moving materials from place to place so as to use up odds and ends, etc.

The contractor was his own foreman and handled his men well. The weather was good, the work being done between April and October, 1904. A 10-hr. day was worked. Natural cement (Louisville) was used.

It will be noted that the excavation for the 20-in. sewer cost less not only per lin. ft. but per cu. yd. than for any of the others. This is due largely to the fact that the trench was shallow, also to the fact that the earth was a heavy, black soil, very easily spaded.

On a short job of 15-in. sewer, 360 ft. long, where the trench was 24 ins. wide and 12.6 ft. deep, in clay that was good spading, the ----- was as follows for excavation:

	Per lin. ft.
Bottom men	$0.299
Top men	0.104
Scaffold men	0.045
Bracing men	0.005
Total	$0.453

This is equivalent to 34.8 cts. per cu. yd.

The backfilling cost 2.8 cts. per cu. yd. additional.

The costs in Table VII are averages of several jobs. The minimum costs of pipe laying on the best of these jobs were as follows per lineal foot:

	8-in.	10-in.	12-in.	15-in.
Pipe layers, at 22½ cts.	$0.009	$0.006	$0.011	$0.015
Helpers, at 17½ cts.	0.007	0.007	0.008	0.009
Total	$0.016	$0.013	$0.019	$0.024

By dividing the pipe layers' hourly wage (22½ cts.) by the costs per lineal foot, we find the total number of feet laid per hour per pipe layer; thus, 22½ ÷ 0.9 = 25 ft. of 8-in. pipe laid per hr. per pipe layer, or 250 ft. per 10-hr. day. In this manner the following table was calculated:

8-in. pipe, 250 ft. per day per pipe layer
10-in. pipe, 375 ft. per day per pipe layer
12-in. pipe, 205 ft. per day per pipe layer
15-in. pipe, 150 ft. per day per pipe layer

It will be noted that the 10-in. pipe was laid with abnormal rapidity in this particular case. On another job, 10-in. pipe was laid at the rate of 250 ft. per day.

TABLE VII.—COST OF PIPE SEWERS, ATLANTIC, IOWA.

	Wage per hr., cts.	8-in.	10-in.	12-in.	15-in.	18-in.	20-in.
Pipe, vitrified	..	$0.135	$0.200	$0.250	$0.330	$0.450	$0.550
Hauling, team and driver	30	0.006	0.003	0.010	0.006	0.005	0.023
Hauling, man helping	17½	0.003	0.001	0.004	0.002	0.001	0.011
Cement and sand	..	0.006	0.006	0.005	0.010	0.015	0.010
Pipe layers	22½	0.012	0.014	0.015	0.015	0.030	0.018
Pipe layers' helpers	17½	0.010	0.014	0.010	0.010	0.021	0.015
Trenching:							
Bottom men	17½	0.150	0.130	0.153	0.125	0.188	0.078
Top men	17½	0.013	0.027	0.014	0.023	0.059	0.004
Scaffolding men	17½	.....	0.002	0.001	0.011	0.012	.....
Bracing men	17½	.....	0.002	0.002	0.001	0.012	.....
Backfilling:							
Men shoveling	17½	0.013	0.010	0.008	0.010	0.035	0.029
Team on scraper	30	0.013	0.008	0.010	0.009	0.017	0.005
Man hold. scraper	17½	0.008	0.005	0.006	0.005	0.010	0.003
Waterboy	10	0.005	0.006	0.005	0.005	0.011	0.008
Foreman	30	0.015	0.022	0.018	0.022	0.046	0.022
Grand total		$0.389	$0.450	$0.517	$0.584	$0.912	$0.776
Total length sewer, ft.		2,850	2,560	3,650	1,125	1,850	2,550
Depth of trench, ft.		10.0	8.2	9.3	9.2	9.6	5.4
Width of trench, ins.		26	30	30	34	35	36
Cu. yds. per lin. ft.		0.82	0.77	0.87	0.95	1.06	0.6
Trenching, cts. per cu. yd.		21.0	22.0	19.0	16.8	27.2	13.7
Backfill, cts. per cu. yd.		4.0	3.2	2.8	2.7	6.2	6.1
Ft. of pipe per bbl. cement		275	425	260	160	100	170

Cost of Pipe Sewers at Centerville, Iowa.— In *Engineering-Contracting*, June 12, Aug. 21, Sept. 18 and Oct. 16, 1907, voluminous tables were published giving the cost of pipe sewers at Centerville. Iowa, the data for which were gathered by Mr. M. A. Hall. The work was done by contract on 161 different jobs, covering more than ten miles of sewer. The average cost of pipe laying, not including trenching, was as follows:

8-in. pipe, 5.0 cts. per lin. ft. (average of 83 jobs).
10-in. pipe, 7.3 cts. per lin. ft. (average of 27 jobs).
12-in. pipe, 7.5 cts. per lin. ft. (average of 41 jobs).
15-in. pipe, 6.7 cts. per lin. ft. (average of 10 jobs).

Apparently none of this work was as well handled as that at Atlantic, Iowa, the data for which have been previously given. Average costs on work so simple as pipe laying, and where no plant is required, often indicate nothing but poor management or laziness. For this reason the following *minimum* costs of work done at Centerville are of more value, as they show what can readily be accomplished:

	8-in.	10-in.	12-in.	15-in.
Pipe layers, at 30 cts.......	$0.010	$0.017	$0.019	$0.016
Helpers, at 17½ cts.......	0.012	0.018	0.011	0.020
Total	$0.022	$0.035	$0.030	$0.036

Even these minimum costs at Centerville are greater than the average costs of pipe laying given above for the work at Atlantic. Iowa. At Atlantic the contractor usually had only one helper to each pipe layer, whereas on this work at Centerville there were usually two helpers to each pipe layer. The wages of the pipe layers at Centerville were nearly 40% higher than at Atlantic, but the helpers received the same wages in both places.

Based upon the above table of minimum cost, the following is the number of lineal feet laid per 10-hr. day by a pipe layer:

8-in. pipe, 300 lin. ft. per pipe layer.
10-in. pipe, 177 lin. ft. per pipe layer.
12-in. pipe, 158 lin. ft. per pipe layer.
15-in. pipe, 188 lin. ft. per pipe layer.

A considerable part (15%) of the work done at Centerville involved trenching in hardpan and hard shale, and there was a little quicksand and some wet weather that caused the banks to cave. All these increased not only the cost of excavating, but also the cost of pipe laying. On the various jobs where the excavation was entirely in shale and hardpan, the cost of laying was 50% more than the average costs above given; so that for 10 and 12-in. pipe the cost of pipe laying was about 11 cts. per lin. ft.

Where quicksand, or a trench soaked from rain, was encountered the cost of pipe laying was similarly increased, that is about 50% above the average cost.

The trenching averaged a cost of 40 cts. per cu. yd. for excavation and 4 cts. per cu. yd. for backfilling, except in shale and hardpan, where the cost was about 70 cts. per cu. yd. for excavation. About 15% of the excavation was shale that could be picked and hardpan. The rest was mostly clay and gumbo, requiring prac-

tically no sheeting. The trenches averaged about 9 ft. deep. The width of the trenches was the same as at Atlantic, above given. Wages averaged 18 cts. per hr. It will be noted that the trenching at Centerville cost practically twice as much per cubic yard as at Atlantic. In view of the fact that the pipe laying also cost twice as much, it would seem that the workmen at Centerville were about half as efficient as those under the contractor at Atlantic.

Foreman's and waterboy's wages are not included in the above given costs for labor of trenching and pipe laying. Foreman received 35 cts. per hr., and waterboys 12½ cts. per hr. Their combined wages amounted to about 10% of the labor cost of trenching, backfilling and pipe laying. This shows that there were one foreman and one waterboy to 25 workmen.

Cost of Pipe Sewers at Laurel, Miss.—In *Engineering-Contracting*, July 24, 1907, the cost of 3 miles of pipe sewers on each of 43 sections was given. The data were secured by Mr. M. A. Hall in the manner previously described under the paragraph relating to sewer work at Atlantic, Iowa.

Negroes were employed and the work was done under inefficient foremen, except on 6 of the sections. The working day was 10 to 11 hrs. long. Common laborers received $1.25 to $1.50 a day, and foremen received $3 to $4 per day.

The excavation was mostly clay, and the average cost of excavation was 30½ cts. per cu. yd., wages being assumed to average 12½ cts. per hr. The backfill was largely done by hand, although teams and scrapers were used on many of the sections. The backfill averaged about 6 cts. per cu. yd. The following were the costs on a few of the sections that showed the lowest costs:

	Per cu. yd.
Excavation of trench 6.3 ft. deep, 1.62 hrs., at 12½ cts.	20.2
Backfill ditto, 0.3 hr. man at 12½ cts. plus 0.06 hr. team and driver at 30 cts.	5.6
Excav. of trench 7.6 ft. deep, 1.80 hrs., at 12½ cts.	22.5
Backfill ditto, 0.24 hr. man, at 12½ cts., plus 0.04 team and driver, at 30 cts.	7.2
Excav. of trench 7.7 ft. deep, 2.07 hrs., at 12½ cts.	26.0
Backfill ditto, 0.12 hr. man, at 12½ cts., plus 0.03 hr. team, and driver, at 30 cts.	2.4

The average costs of pipe laying were as follows per lin. ft., wages being assumed to be 20 cts. for pipe layers and 12½ cts. for helpers:

	8-in.	10-in.	12-in.	18-in.	20-in.
Pipe layer, at 20 cts.	$0.010	$0.012	$0.011	$0.015	$0.012
Helper, at 12½ cts.	0.013	0.012	0.018	0.026	0.022
Total	$0.023	$0.024	$0.029	$0.041	$0.034
Number of sections	31	3	2	5	2

There were, ordinarily, two helpers to each pipe layer.

For comparison with the above averages, the following minimum costs of pipe laying on certain sections are given:

	8-in.	10-in.	12-in.	18-in.	20-in.
Pipelayer, at 20 cts.	$0.005	$0.010	$0.009	$0.008	$0.012
Helper, at 12½ cts.	0.008	0.012	0.015	0.018	0.022
Total	$0.013	$0.022	$0.024	$0.026	$0.034

That these minimum costs vary so slightly from the average costs on sections other than for the 8-in. pipe is due to the fact that there were so few sections where sizes larger than 8-in. were laid.

Estimated Cost of Pipe Sewers. — In *Engineering-Contracting*, April 1, 1908, the Table VII A was published. The estimated costs given in this table are said to be based upon the actual costs of 51 miles of sewers built in five cities where the physical conditions were similar to those at Clinton, Iowa, as compiled by Mr. Charles P. Chase, city engineer of Clinton. The table gives the estimated cost per lin. ft., not including the cost of excavation, nor foremanship and incidentals.

I have omitted the item of "foreman" from the above table. Foreman's salary usually amounts to 5 to 10% of the *labor*—not 5 to 10% of the *labor and materials.*

I have also omitted an item of "interest and incidentals," which Mr. Chase estimates at 10% of the total cost of labor and materials. Interest on money invested is a very small item where the contractor receives monthly payments, and a percentage for "incidentals" should apply only to the labor.

Mr. Chase calls the total of the above items a "constant," and to this "constant" he adds the cost of trenching, which is the "variable."

There is an error in the item of laying 36-in. pipe, as will be seen by comparison with the corresponding item for 30-in. pipe. The item of "shipping loss and haul" appears to be much overestimated; so also is the item of "lights and watchman."

Cost of a Pipe Sewer in Quicksand.—The following data were published in *Engineering-Contracting*, June 3, 1908.

Wildwood is a new summer resort town, built a few years ago on the southern end of an island called Five Mile Beach, on the New Jersey coast. Prior to the building of the town the site was covered at high tide by 3 ft. of water. The soil was black mud covered with thick meadow sod, with, here and there, piles of sand which were shifted by the tide. The first work done was to build a bulkhead and by means of dredges to raise the land above the high tide. Then the building of the town and resorts began.

To serve the buildings, a system of terra cotta pipe sewers was built. The trench for the entire distance, 12 miles, was through quicksand, from which water bubbled, and known locally as "boiling sand." This makes both expensive and difficult work, adding to the cost of laying the pipe, as it is difficult to keep the pipes at the proper grade and in good alignment, and the joints are hard to caulk, owing to the water in the ditch.

The greatest cutting was 6½ ft. deep and the entire trench was double sheeted throughout, great trouble being experienced in keeping the trench even partially dry. Sumps or wells could not be made, as the pumps pulled out so much sand under the sheeting as to cause either the ditch to fill or the sheeting to cave in.

The sheeting was put down to a depth of 10 ft. with a water jet in advance of the excavation, this being the only way the contractor could make any headway. Owing to the numerous "salt

TABLE VII A.—COST OF PIPE SEWERS.

	6-in.	8-in.	10-in.	12-in.	15-in.	18-in.	20-in.	22-in.	24-in.	27-in.	30-in.	36-in.
	$	$	$	$	$	$	$	$	$	$	$	$
Pipe	.080	.116	.174	.218	.340	.510	.683	0.819	0.975	1.500	1.600	2.700
10% extra Y's..........	.008	.015	.023	.028	.040	.056	.072	0.122	0.122	0.150	0.150	0.270
Shipping loss and haul..	.005	.012	.020	.024	.034	.046	.057	0.070	0.080	0.120	0.140	0.150
Cement and sand	.003	.006	.009	.010	.013	.020	.022	0.030	0.030	0.036	0.043	0.100
Labor laying	.045	.045	.050	.075	.080	.085	.100	0.120	0.130	0.150	0.180	0.100
Lights and watchman..	.010	.010	.010	.015	.017	.020	.022	0.025	0.030	0.040	0.050	0.070
Insurance	.003	.004	.005	.005	.006	.007	.007	0.008	0.009	0.010	0.015	0.020
Injury to water cos....	.010	.012	.014	.016	.018	.020	.022	0.024	0.026	0.028	0.030	0.034
Cost of $50,000 bond...	.005	.005	.005	.005	.005	.005	.005	0.005	0.005	0.005	0.005	0.005
Total	.169	.225	.310	.396	.553	.769	.990	1.223	1.407	2.039	2.213	3.449

holes" encountered, through which the line at time ran, it was necessary to make a foundation for the manholes and pipe. This was done by piling spaced 7 ft. apart and 6 in. c. to c. On the piles 4 x 4 yellow pine, 8 ft. long, was spiked, and to this was spiked hemlock planks 2 x 8—12 ft. long. The pipe was laid on this and the hole filled with sand and salt hay.

If a manhole was located at one of these "salt holes," 4 piles, 10 to 15 ft. long were driven 4½ ft. c. to c. Four railroad ties were then spiked together with two pieces of batten, and the whole bolted securely to the piles. On this foundation was placed a box 5 ft. square and 10 ins. deep, the bottom being covered with tongue and grooved floor boards, and in some cases lined with canvas and the inside covered with coal tar pitch. The concrete was placed in the box, the pipe line run through, and the brick work completed.

As a general rule, water was struck in excavating the trench about 18 ins. below the surface. The pipe laid was 8 and 12 in.

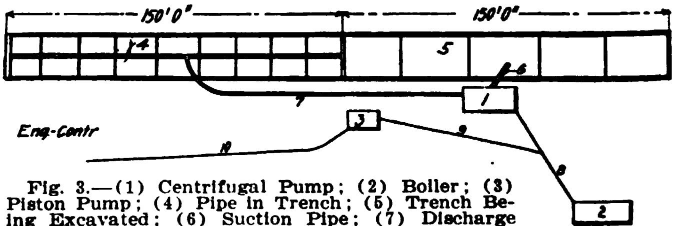


Fig. 3.—(1) Centrifugal Pump; (2) Boiler; (3) Piston Pump; (4) Pipe in Trench; (5) Trench Being Excavated; (6) Suction Pipe; (7) Discharge Pipe; (8) and (9) Steam Pipes; (10) Pipe to Water Supply.

terra cotta, hence the ditch was made only wide enough for a man to work in it easily, this width being 2 ft. for a ditch 6 to 7 ft. in depth.

The method of excavating was as follows: By using the piston pump the sheathing was put down for a distance of 150 ft. along the trench, and a closure made at each end. Then 10 laborers were put in the trench and excavation made to the water line, when rangers and braces were set.

The piston pump was then started pumping water into this "land coffer dam." A centrifugal pump was moved into position, and the discharge pipe placed midway in the last section, where the sewer pipe had already been laid. Thus the centrifugal pump excavated the material from the forward section and backfilled the last section at the same time. See Fig. 3.

When grade was reached, the foundation piles were jetted down and the cradle constructed. The pipe was then laid, the joints being made with cement and tar. The next section was then done in the same manner.

The sand excavated was quite coarse, and but little agitation was necessary with shovels, in order to allow the pump to pick up the sand. When the sand is fine grained, much more water is needed,

and likewise the sand must be agitated with shovels. With extremely fine sand, the men must be relieved frequently, as the work is hard, and, as the pumps take up a much smaller percentage of the sand, the ditch must be kept with a larger amount of water in it, and the men, being compelled to stand in the water, feel the effect of it quickly.

At times when the contractor got as deep in the trench as the original ground surface, he encountered a considerable number of roots that had to be cut out, but this was seldom necessary.

Fig. 3 shows the layout of the plant to do the work in the manner described. In this way an average of 300 lin. ft. of trench was dug and pipe laid per day, while another contractor doing similar work by another method averaged only from 35 to 50 ft. per day.

The cost of driving the sheeting and pulling it for the 300 lin. ft. of trench done per day was:

Boss timberman	$ 2.50
Fireman on jet pump	1.50
One man setting sheeting	2.00
Two helpers, at $1.50	3.00
Three men pulling sheeting, at $1.50	4.50
One man carrying sheeting	1.50
Two men bracing trench, at $2.00	4.00
One man pumping	1.75
Coal and oil	1.00
Total	$21.75

This gives a cost per lin. ft. of trench of 7 cts. for driving and pulling sheeting, and as there was 6,080 lin ft. of sheeting driven and pulled a day, it makes a cost per lin. ft. of sheeting ⅓-ct. With 2-in. sheeting used, the amount of timber was 6,000 ft. B. M., which cost $26 per M. This timber, being driven with a water jet, was used time and time again. The sound piles, which were from 10 to 15 ft. long, cost 25 cts. apiece, and the cost of driving them was 1.5 cts. per lin. ft.

The cradle for the pipe was built by two men, each at $2 per day. They built 200 lin. ft. per day, which meant a cost per ft. of trench of 2 cts. The amount of lumber in 200 ft. of cradle was 866 ft. B. M., which meant a labor cost for framing of about $5 per M. The lumber cost $26 per M.

The daily cost of digging the trench and backfilling, and of laying the pipe was:

Foreman, 10 hrs	$ 4.00
Eight men digging, at $1.50	12.00
Two men trimming, at $1.50	3.00
One engineman	3.00
One pumper	2.50
Two pipemen, at $2.00	4.00
Coal, at $5.00 per ton	1.25
Rent of boiler	2.00
Rent of pumps	2.50
Rent of engine	2.00
Two pipelayers, at $2.00	4.00
Two pipe carriers, at $1.50	3.00
One man on mortar and jute	1.50
Total	$44.75

The excavation and backfilling done by the pumper can be listed as follows:

Cost per lin. ft. of trench:

Labor	$0.032
Coal	0.004
Plant rental	0.022
Total	$0.058

Each day this plant excavated about 200 cu. yds., hence the cost per cu. yd. was:

Labor	$0.047
Coal	0.006
Plant rental	0.032
Total	$0.085

This is a very low cost for excavating earth from a trench and backfilling it.

The terra cotta pipe cost 16 cts. per lin. ft. and the hauling of it cost 2 cts.

The total cost per lin. ft. of pipe laid was as follows, exclusive of manholes:

Foreman		$0.013
Excavating and backfilling by hand		0.050
Excavating and backfilling by pump:		
Labor	$0.032	
Coal	0.004	
Plant rental	0.022	0.058
Driving sheeting		0.040
Bracing trench		0.013
Pulling and carrying sheeting		0.020
Piles in place		0.105
Cradle, lumber and labor		0.132
Pipe		0.160
Hauling pipe		0.020
Laying pipe		0.028
Materials for joints		0.013
Total		$0.652

This cost does not include any allowance for general expense nor for the materials used in shoring the sides of the trenches. The sheeting was used many times, as driving the planks with a water jet did not injure the planks or break them up.

The cost of a manhole was as follows:

Cover and frame	$ 9.00
Bricklayer	2.00
Bricks, 1,500, at $10 per M	15.00
Stone, ¾ cu. yd., at $1.00	.75
Cement, 3 bags, at 50 cts	1.50
Pumping	1.12
Labor, excavating	3.18
Sheeting, etc.	2.17
Total	$34.72

The cost of this work in a ground difficult to excavate is exceedingly low, and can be attributed to the methods used in carrying on the work.

Mr. George L. Watson, M. Can. Soc. C. E., was chief engineer of the Wildwood Sewer Co., and designed the entire improvement made, including the sewers. He afterwards associated himself with the

contractor for the sewers, Mr. Alexander Murdock; and, as engineer in charge, decided upon and put into operation the method used.

Cost of Two Pipe Sewers and Manholes at Oskaloosa, Ia.*—The following cost data relate to the construction of a 12-in. sanitary sewer in Sixth avenue, and an 8-in. sewer in South Market street, Oskaloosa, Ia.

The Sixth avenue sewer consisted of 1,004 lin. ft. of 12-in. pipe (tile), five manholes and one lamphole. The work required the excavation of 1,063.8 cu. yds. of material, the average depth being 11.4 ft. and the maximum depth 16 ft. On this sewer there were about 250 ft. of trench in which the depth was from 13 to 15 ft. This necessitated handling part of the earth three times before it was removed from the trench, which added considerably to the cost of excavation. The cost of the 1,004 lin. ft. of 12-in. sewer was as follows:

Cost of 12-in Sewer.

	Total.	Per lin. ft. Sewer.
Labor:		
Trenching	$ 543.90	$0.541
Sheeting	72.00	.072
Laying pipe	46.38	.046
Backfilling	93.65	.093
Miscellaneous expense, laying pavement, hauling, etc.	45.00	.045
Total, labor	$ 800.93	$0.797
Materials:		
Lumber for sheeting	$ 32.30	$0.032
Cement for joints, 15 sacks	5.40	.005
Sand for joints, 30 bu.	1.80	.002
Jute calking, 50 lbs.	3.50	.003
Pipe, 958 lin. ft.	249.08	.248
Specials, 14, at $0.72	10.08	.010
Total, materials	$ 302.16	$0.301
One lamp hole, 13 ft. deep	4.20	.004
Five manholes	274.82	.274
Grand total	$1,382.11	$1.377

In the above work there was 980 lin. ft. of trenching, the cost per lin. ft. being $0.555. The cost of sheeting the 980 lin. ft. of trench was:

	Total.	Per lin. ft. Trench.
Labor	$ 72.00	$0.073
Lumber	32.30	.033
Total	$104.30	$0.106

There were 400 joints, requiring 15 sacks of cement and 30 bushels of sand, the cost per joint being $0.018. The calking for the 400 joints took 50 lbs. of jute, or .125 lb. per joint, and cost $0.009 per joint.

The South Market street sewer consisted of 816.8 lin. ft. of 8-in. tile, two manholes and one lamphole. There were 365.9 cu. yds.

**Engineering-Contracting*, Sept. 23, 1908.

of excavation. the average depth being 6.6 ft., and the maximum depth 10.6 ft. The cost of this sewer was as follows:

Cost of 8-in. Sewer.

	Total.	Per lin ft. Sewer.
Trenching	$113.40	$0.139
Sheeting trench and miscellaneous	15.00	.018
Laying pipe	21.25	.026
Backfilling	15.25	.019
Cement for joints, 6 sacks......	2.16	.002
Sand for joints, 20 bu..........	1.20	.001
Pipe, 780 lin. ft..............	121.60	.149
Specials, 18, at $0.72..........	12.96	.016
Total	$302.90	$0.369
One lamp hole, 10 ft. deep......	4.30	.005
Two manholes	64.89	.081
Grand total	$372.09	$0.455

There was 805.6 lin. ft. of trenching, the cost per lin. ft. being $0.14. There were 327 joints, requiring six sacks of cement and 20 bushels of sand, the cost per joint being $0.011.

In the above work the cost of laying tile includes taking out the last spading from the bottom of the trench, and tamping same about tile previously laid. Each tile was laid to line and grade from a grade cord supported over trench, the supports consisting of two upright 2 x 4 pieces, and cross board, spaced 25 ft. apart. Joints were calked and cemented, bevel pattern, with 1:1 Portland cement mortar.

The backfilling was done with team and scraper and two men. Earth was first put in the trench to within about 1 ft. of the top. and the trench then flooded with the fire hose. The balance of the earth was then scraped onto the trench. This has proven a very satisfactory method, as practically all of the earth goes back into the trench in a short time.

The soil consists of from 1 to 3 ft. of black loam on the surface, under which is tough clay. As the ground this summer contained very little water, only skeleton bracing was used.

Prices and Wages.

The prices of materials delivered on the work were as follows:

Cast-iron manhole and lamphole covers, $0.025 per lb.

Wrought-iron manhole steps, $0.24 each.

No. 1 vitrified paving brick, $11.00 per M.

Cement, $0.36 per sack.

Sand, $0.06 per bu., 100 lbs. per bu.

Jute calking, $0.07 per lb.

8-in. tile, $0.156 per lin. ft.

10-in. tile, $0.26 per lin. ft.

Oak lumber, $38.50 per M.

The wages paid were as follows:
Brick masons, $0.55 per hour for 8 hours.
Tile layer, $2.50 per day.
Common labor, $0.20 per hour for 9 hours.
Team and driver for backfilling, $0.40 per hour.

Cost of Manholes.

The manholes were built of No. 1 vitrified paving brick on a foundation of 1:4:8 concrete from 8 in. to 1 ft. thick under the walls. Portland cement mortar mixed 1:2 was used in building walls, all joints being slushed full. The walls were 13 in. thick at depths greater than about 12 ft. and 9 in. thick above this depth.

Below is given cost of two manholes of different depths:

Manhole 16.5 ft. deep, requiring 20.4 cu. yds. excavation.

Excavation:	
Labor, at $0.20 per hour	$ 9.40
Foundation:	
Labor, at $0.20 per hour	2.40
3 sacks cement, at $0.36 per sack	1.08
0.4 cu. yd. sand, at $1.40 per yd	0.56
1 cu. yd. crushed brick, at $2.30 per cu. yd.	2.30
Superstructure Manhole:	
2,400 brick, at $11.00 per M	26.40
16 sacks cement, at $0.36 per sack	5.76
26 bu. sand, at $0.06 per bu	1.56
1 C. I. cover, 307 lbs., at $0.025 per lb.	7.68
1 dust pan, 50 lbs., at $0.025 per lb	1.25
8 steps, at $0.24 each	1.92
2 pieces split tile in bottom	0.65
Brick mason, 10 hrs., at $0.55 per hr	5.50
Hod carriers, at $0.20 per hr	6.00
Total cost of manhole	$72.46

Manhole 8.4 ft. deep, requiring 8.2 cu. yds. excavation.

Excavation:	
1 man 13 hrs., at $0.20 per hr	$ 2.60
Foundation:	
Labor, at $0.20 per hr	0.80
2 sacks cement, at $0.36 per sack	0.72
.25 cu. yd. sand, at $1.40 per cu. yd	0.35
.5 cu. yd. crushed brick, at $2.30 per cu. yd.	1.15
Superstructure Manhole:	
1,100 brick, at $11.00 per M	12.10
6 sacks cement, at $0.36 per sack	2.16
10 bu. sand, at $0.06 per bu	0.60
1 C. I. cover, 307 ft., at $0.025 per lb.	7.68
1 dust pan, 50 lbs., at $0.025 per lb	1.25
3 steps, at $0.24 each	0.72
2 pieces split tile in bottom	0.40
Brick mason, 8 hrs., at $0.55 per hr	4.40
Hod carriers, at $0.20 per hr	1.60
Total cost of manhole	$36.53

All of the above work was done this summer by lay labor under the supervision of Mr. E F. Bridges, City Engineer, to whom we are indebted for the information from which this article was prepared.

Cost of Two Pipe Sewers.*—The following costs relate to two small jobs of 8-in. pipe sewer constructed during 1908 at Fredericton, N. B. The work was done by day labor and the wages paid were:

	Cents.
Foreman, per hour	30
Laborers, per hour	18
Single team, per hour	27
Double team, per hour	50

A 9-hour day was worked. The 8-in. terra cotta pipe cost 22½ cts. per foot. and Gillingham cement cost $2.10 per barrel delivered on the work. Lumber for studding cost $16.50 per 1,000 ft. B. M. The manholes were elliptical 4 ft. x 3 ft. in diameter with 8-in. brick walls and 12-in. tube.

Waterloo Road Sewer.—This job comprised 495 ft. of 8-in. pipe sewer with 2 manholes. The average depth of trench was 9.7 ft. It cost as follows:

Item.	Total.	Per unit.
5.98 cu. yds. brick work	$ 83.10	$13.85
533.5 cu. yds. excavation	274.97	0.515
Laying 8-in. pipe (495 lin. ft.)	20.72	0.04

The cost of the sewer, including sheeting, which is lumped with excavation in the above costs, was $0.93 per lin. ft. The trench had to be close sheeted every foot of its length, the material being sand and the bottom 4 ft. wide.

Phoenix Square Sewer.—This job comprised 811 ft. of 8-in. pipe sewer, with 3 manholes. The average depth of trench was 5.8 ft. in sand and loam, which had to be braced about every 4 to 6 ft. The trench was dry. The cost of the work was as follows:

Item.	Total.	Per unit.
4.32 cu. yds. brick work	$ 54.00	$12.50
522.5 cu. yds. excavation	195.30	0.374
Pipe laying (811 ft.)	27.70	0.034

The total cost of the sewer was $425.15 or $0.52 per lin. ft.

We are indebted for the above information to A. K. Grimmer, city engineer, Fredericton, N. B.

Cost of 8-in. to 18-in. Sewers at Cardele, Ga.—In Engineering News, March 30, 1893, Mr. Geo. G. Earl, C. E., gives the cost of some pipe sewer work at Cardele, Ga. Wages were 80 cts. to $1 per day for labor (presumably negroes) and the foreman received $70 a month.

**Engineering-Contracting*, Aug. 25, 1909.

Size of pipe.	Depth of cut in ft.	Length in ft.	Cost of labor, cts. per ft.	Cost of foreman, cts. per ft.
8 inches	[illegible]	1,195	14.1	1.0
8 inches	[illegible]	[illegible]	22.8	1.9
8 inches	[illegible]	[illegible]	33.8	1.9
8 inches	[illegible]	457	35.2	5.8
10 inches	[illegible]	[illegible]	26.7	...
10 inches	[illegible]	[illegible]	35.5	1.6
12 inches	[illegible]	1,944	27.0	1.1
15 inches	[illegible]	963	33.5	1.7
18 inches	10.6	867	79.2	4.0

The "Cost of Labor" given in the fourth column includes trenching, pipe laying and backfilling.

In building 2.6 miles of sewer (2 miles of which were 8-in.) and 35 manholes, the total cost was:

Labor	$3,867
Masons and helpers..............................	462
Sundries	17
Foreman	266
Supervision	1,000
Pipe	2,635
Brick	252
Cement	166
Hauling	82
Manhole covers	289
Tools and incidentals............................	561
Total	$9,596

It will be noted that the foreman's wages amounted to about 6% of the total wages paid to laborers and masons.

Cost of a 12-In. Pipe Sewer, Menasha, Wis.—In 1903, some pipe sewers were built in Menasha, Wis., by day labor. I am indebted to Mr. S. S. Little for the following data: There were 2,200 ft. of trench, about half of which was for 12-in. pipe and half for 15-in. pipe. The depth of trench ranged from 7½ to 10 ft., averaging 9 ft., and the width was 2 ft. The material was solid red clay. Wages paid were $1.75 per 10-hr. day. Some team work, at $3.50 a day, was used in scraping in the backfill. The labor of trenching, laying pipe, and backfilling averaged 37 cts. per lin. ft. of trench. If the pipe laying cost 4 cts. per ft., the cost of trenching and backfilling was 33 cts. per ft., or 50 cts. per cu. yd.

Cost of 8-In. Sewer at Ithaca, N. Y.—In Engineering News, Aug. 20, 1896, Mr. H. N. Ogden, C. E., gives the following costs of trenching and laying 8-in. sewer pipe in Ithaca, N. Y.: The column of labor cost is based on daily wages of $1.35 for laborers, $1.50 for pipe layers, and $2 for foreman. Mr. Ogden has kindly informed the writer that the working day was 10 hours long. Teams were paid $3.50, masons on manholes, $3.50, and masons' helpers, $1.50; 8-in. sewer pipe cost 12½ cts. per ft. Natural cement, at 95 cts. per bbl., laid 120 to 243 ft. of pipe per bbl. (Doubtless neat cement mortar was used.) The work was by contract, and not all under

the same foreman; hence the variation in cost shown in the table.

Name of street.	Length laid.	Depth of trench in ft.	Material.	No. of day's work.	—Cost of labor.— Total.	Per ft.
Wheat	1,134	5.3	[1]	4	$126.50	$0.11
Corn	1,504	5.8	[2]	5	200.70	.12
Washington	398	4.9	[3]	1½	49.50	.12
Titus	1,391	6.8	[4]	4½	318.90	.23
Plain	1,332	5.9	[5]	7	209.00	.16
Buffalo	597	6.7	[6]	4	108.25	.18
Fayette	984	5.6	[7]	4	195.05	.20
Centre	1,334	6.8	[8]	7	347.00	.26
Green	1,919	5.7	[9]	11	418.85	.22
Clinton	2,403	5.4	[10]	11	519.85	.22
Albany	1,431	5.0	[11]	9	319.50	.22
Geneva	1,323	5.3	[12]	7	373.47	.28
Cayuga	1,413	6.3	[13]	10	468.25	.33

[1] Wet clay; water 3 ft. down, bailed out.
[2] Wet clay; water 3 ft. down, bailed out, occasional bracing.
[3] Wet clay.
[4] Loam over wet clay; water 6 ft. down; occasional bracing.
[5] Wet clay; water 5 ft. down; diaphragm pump; occasional bracing.
[6] Clay and gravel; much water in places; pump; braced.
[7] Wet clay; water 4 ft. down; occasional bracing and pumping.
[8] Wet clay; water 3 ft. down; 1 diaphragm; occasional bracing.
[9] Half clay, half gravel; half close sheeted; underdrain pumps.
[10] Wet clay, some gravel pockets; 1 pump; some bracing.
[11] Gravel containing water at 5 ft.; pump; half sheeted.
[12] Sheeting and pumping entire; water at 5 ft.
[13] Loose gravel; brick pavement removed; half braced and half sheeted.

Cost of 12-in. Sewers in Toronto, Canada.—A large number of 12-in. pipe sewers were built by day labor for the city of Toronto in 1891, at the following costs:

Average depth.	Soil.	Length, feet.	Manholes.	Catch-basins.	Connections.	Cost per foot.
10′ 10″	Quicksand	1,041	5	6	15	$1.95
11′ 2″	Clay	4,427	19	21	240	1.27
18′ 0″	Blue clay	650	3	..	..	2.11
12′ 1″	"	180	1	..	15	2.20
11′ 6″	"	251	.	..	4	2.41
8′ 1″	"	800	3	4	29	1.33
9′ 9″	"	483	4	2	24	1.78
11′ 2″	Clay loam	430	2	2	13	0.96
10′ 8″	"	357	3	..	17	1.90
11′ 0″	Hardpan	320	2	2	18	1.28
11′ 3″	Sand	535	3	2	5	1.50
11′ 4″	Av. of above	9,474	45	39	380	$1.51

The cost per ft. includes all materials, labor and inspection of work. It also includes the manholes and catch-basins, and the Y-connections. The 12-in. pipe cost 22 cts. per ft.; brick was $8.50 per M. Laborers were paid 15 cts. per hr., and a few special men were paid 18 cts. per hr.; bricklayers were paid 40 cts. per hr.

Contract Labor Costs at Providence, R. I.—During 1906 there were 2.263 miles of regular sewers built at Providence, R. I., of which 1.751 miles were of pipe and .512 miles were of brick. The average depth of cut, nature of excavation and contract cost of

labor per foot on the different sizes of sewers built during 1906 are given in the annual report of the city engineer as being as follows:

Nature of Excavation.	Average depth of cut, ft.	Average cost per ft.
6-in. pipe[1]—Fine sand, dry	10.50	$0.45
6-in. pipe[1]—Fine sand, wet	10.50	.49
6-in. pipe[1]—Sand and gravel, dry	10.50	.41
6-in. pipe[1]—Hard pan, wet	10.50	.60
6-in. pipe[1]—Hard pan and rock	10.50	.35
8-in. pipe[2]—Fine sand, dry	8.00	.40
8-in. pipe[2]—Fine sand, wet	8.00	.45
8-in. pipe[2]—Sand and gravel, dry	8.00	.40
8-in. pipe[2]—Hard pan, wet	8.00	.45
8-in. sewer—Fine sand, dry	11.67	.30
8-in. sewer—Sand and gravel	11.67	.70
8-in. sewer—Filling, dry	11.67	.60
12-in. sewer—Fine sand, dry	12.00	.60
12-in. sewer—Fine sand, wet	12.00	.85
12-in. sewer—Sand and gravel, dry	12.00	.62
12-in. sewer—Hard pan, wet	12.00	.60
12-in. sewer—Hard pan and rock	12.00	.35
15-in. sewer—Sand and gravel, dry	12.25	.75
15-in. sewer—Hard pan, wet	12.25	1.00
20-in. brick sewer—Hard pan and rock, wet	12.67	2.00
22-in. brick sewer—Hard pan, sand and rock, dry	12.83	.65
24-in. brick sewer—Sand and gravel, wet	13.00	3.00
30-in. brick sewer—Sand and gravel, wet	13.50	4.00
36-in. iron pipe—Mud, wet	14.00	6.50
70-in. brick and concrete—Sand and gravel, wet	18.00	8.00
70-in. brick and concrete—Sand and gravel, wet	[3]	30.00
84-in. brick and concrete—Mud, wet	14.00	8.00
84-in. brick and concrete—Sand and gravel, wet	20.00	20.00

[1] In drains to curb line. [2] In basin connections. [3] In tunnel.

The average labor cost of building each manhole was $10.65, each catch-basin $11.07, and each extra inlet $9.00.

Brick Sewer Data.—Brick sewers are either "circular" or "egg-shape." In either case the upper part of the sewer is called the "arch," and the lower part is called the "invert." The depth of a brick sewer, as given on profiles, is the depth from the surface of the street to the inside of the bottom of the sewer, so that the thickness of the sewer invert should be added to secure the full depth of the trench. The thickness of a brick sewer is usually expressed in "rings." A "one-ring" sewer is made one brick thick; that is, 4 ins. thick plus the cement plaster which is usually ½-in. thick; so that a one-ring sewer is 4½ ins. thick. A two-ring sewer is two bricks, or 9 ins. thick. A three-ring sewer is three bricks, or 13½ ins. thick.

The size of a sewer is denoted by its inside diameter.

Brick sewers, like pipe sewers, are usually paid for by the lineal foot of sewer including trenching; but it is desirable always to calculate the brickwork in cubic yards. Table VIII gives the

number of cubic yards of brick masonry per lineal foot of circular sewer.

For intermediate sizes interpolate between the values given in the table.

To calculate the number of cubic yards per lineal foot of any circular sewer, proceed as follows: Add the inside diameter in feet to the thickness of the sewer in feet; this gives the "average diameter." Multiply this "average diameter" by 3 1/7, or 3.14; then multiply the quotient by the thickness of the sewer in feet and divide by 27.

For example, a 5-ft. sewer has walls 9 ins. thick (it is a "two-ring" sewer); and, as 9 ins. = ¾ ft., we have by the rule: 5 + ¾ = 5¾ as the "average diameter"; then 5¾ × 3 1/7 × ¾ ÷ 27 = ½ cu. yd. per lin. ft.

Sewer bricks are of a better quality than common building bricks, and usually cost $1 per M more than common bricks. Ordinarily about 500 bricks are required per cubic yard, but the variation may be 15% greater or less, due to the fact that the sizes of bricks differ in different localities. About 2% is usually added to cover the wastage.

Since the joints are V-shaped, and since the inside of the sewer is usually plastered, more mortar is required than in plain brick-work. About 0.35 to 0.4 cu. yd. of mortar is required per cu. yd. of brick masonry. The number of barrels of cement required to make 1 cu. yd. of mortar is given on page 253.

In building 5-ft. circular sewers at Lawrence, Mass., in 1886, 1 part natural cement to 1½ parts sand was used; and it required 2½ bbls. of cement per thousand bricks.

At Newton, Mass., a 24 x 36-in. egg-shaped sewer required 1.5 bbls. of cement per cu. yd., the mortar being mixed 1:1½. There were 509 bricks per cu. yd. of sewer masonry, not including the waste; and 520 bricks including waste.

At Los Angeles, two-ring 40-in. circular sewers required 0.4 bbl. Portland cement per lineal foot of sewer, which is equivalent to 1.12 bbls. cement per cu. yd. of brick masonry. The mortar was 1 part cement to 2 parts sand.

Mr. Desmond Fitzgerald gives the following as averages of cost of brick sewer work done by certain contractors at Boston, prior to 1894:

	Per cu. yd.	
Labor	$ 2.89	$ 3.40
Brick (560 to 580 per cu. yd.), at $9.50 per M.	5.48	5.30
Sand	0.30	0.40
Natural cement, 1.27 bbls., at $1.13	1.35	1.50
Centers	0.23	.20
Miscellaneous	0.19	.20
Total per cu. yd.	$10.44	$11.00

The first example is the cost of a well-handled job of 1,300 cu. yds. of brick masonry. The second example is the average of several jobs. Brick cost $9.50 per M; and natural cement $1.13 per bbl. The mortar was probably mixed 1:1½, that is 1 part

cement to 1½ parts sand. Wages of bricklayers were probably 50 cts. per hr., and helpers 15 to 20 cts. per hr.

TABLE VIII.—BRICK MASONRY IN CIRCULAR SEWERS, CU. YDS. PER LINEAL FT.

Diameter. Ft.	Ins.	One-Ring (4½ ins.)	Two-Ring (9 ins.)	Three-Ring (13½ ins.)
2	0	0.103	0.240	.....
2	3	.114	.261	.....
2	6	.125	.280	.....
2	9	.136	.305	.....
3	0	.147	.327	.....
3	3	.158	.349	.....
3	6	.169	.371	.....
3	9	.180	.393	.....
4	0	.191	.415	.....
4	3	.202	.436	.....
4	6	.213	.458	.....
4	9	.223	.480	.....
5	0	.234	.501	.802
5	3	.245	.523	.834
5	6	.256	.545	.867
5	9	.267	.567	.900
6	0	.278	.589	.933
6	3	....	.611	.966
6	6	....	.633	1.000
6	9	....	.655	1.031
7	0	....	.677	1.063
7	6	....	.720	1.128
8	0	....	.763	1.193
8	6	....	.807	1.260
9	0	....	.851	1.325
9	6	....	.895	1.390
10	0	....	.938	1.456

TABLE IX.—BRICK MASONRY IN EGG-SHAPED SEWERS, CU. YDS. PER LINEAL FT.

Dimensions Ins.	One-Ring (4½ ins.)	Two-Ring (9 ins.)	Three-Ring (13½ ins.)
12 x 18	0.071	0.176	....
14 x 21	.081	.194	....
16 x 24	.090	.212	....
18 x 27	.099	.231	....
20 x 30	.108	.249	....
22 x 33	.117	.267	....
24 x 36	.126	.286	....
26 x 39	.136	.304	....
28 x 42	.145	.322	....
30 x 45	.154	.341	....
32 x 48	.163	.359	....
34 x 51	.172	.374	....
36 x 54	.182	.396	....
38 x 57	.191	.414	....
40 x 60	.200	.433	0.698
42 x 63	....	.451	.725
44 x 66	....	.469	.753
46 x 69	....	.488	.781
48 x 72	....	.506	.808
50 x 75	....	.524	.836
52 x 78	....	.543	.863
54 x 81	....	.561	.891
56 x 84	....	.579	.918
58 x 87	....	.598	.946
60 x 90	....	.616	.973

Bricklayers on sewer work often receive abnormally high wages. In some cities the labor unions have forced up the price to $1 per hour. In such cases a bricklayer is usually required to lay not less than 3,000 or 4,000 bricks a day; and I have known as high as 5,000 bricks to be laid by skilful and rapid layers.

The dimensions of egg-shaped sewers are given in terms of the inside diameter of the upper arch, and the inside height of the sewer; thus a 30 x 45-in. sewer, is one having an upper arch 30 ins. inside diameter and an inside height of 45 ins. The Phillips Metropolitan Standard (English) egg-shaped sewer has an inside height which is 1½ times the diameter of the arch. Calling the diameter of the arch d, the other dimensions are:

Radius of invert........................	¼ d
Radius of side........................	1½ d
Height	1½ d
Area of waterway........................	1.15 d^2
Perimeter	3.96 d

The first dimension given in the first column of Table VIII is d. The table gives the number of cubic yards of masonry per lin. ft. of egg-shaped sewer.

Cost of Large Brick Sewers, Denver, Colo.—Mr. W. W. Follett gives the following data on brick and concrete sewers built by day labor in Denver, Colo.: Work was begun August, 1894, and finished June, 1895. Work was carried on in the winter, which added somewhat to the cost. The wages paid were high and the hours of labor short. The men were considered to be efficient. The following were the number of day's work performed and the wages per 8-hr. day:

726 days, foremen, at $3.33⅓ to $5.
1,398 days, stone masons, at $3.60.
1,491 days, brick masons, at $4.00.
385 days, watchmen, blacksmiths, and timbermen, at $2.50.
8,115 days, labor, at $2.00.
7,628 days, labor, at $1.75.
363 days, waterboys, at $1.00 to $1.25.
2,150 days, team with driver, at $3.50.
252 days, enginemen and pumpers, at $3.00.

See Table X.

Note.—Sec. 1 was built in filled ground containing city refuse. The original ground was about level with the invert, and had been filled with 2 to 5 ft. of refuse. The bottom of the trench was 2 to 4 ft. below the level of a river near by, so that there was much pumping. The backfill was largely hauled in with wagons, as the material from the trench was not a suitable backfill. The sewer had a concrete base 8 ins. thick and 16 ft. wide, on top of which was a stone cradle. The invert was a single ring of brick, and the arch was three rings.

Sec. 3 was nearly all in good ground, but there was water all along it. The cross-section of the sewer was the same as in Sec. 1, except with less diameter, giving about 80% as much material.

Sec. 6 contained rock for its full length, but the rock was very soft, being in places hardly more than indurated clay. The trench

TABLE X.—COST OF BRICK AND CONCRETE SEWERS, DENVER, COLO.

	Sec. 1.	Sec. 3.	Sec. 5.	Sec. 6.	Sec. 7.	Sec. 8.	Sec. 9.	Secs. 7, 8, 9.
Diameter, ins.	94	70	70	70	77	77	77	77
Length, ft.	2,394	1,714	211	503	947	1,396	1,094	3,437
Depth of trench, ft.	.....	.....	.....	11.0	11.0	12.5	14.0	.....
Cu. yds. earth excavation, per ft.	3.33	1.25	1.2	3.0	4.0	5.5	7.0	.....
Cu. yds. rock excavatiton, per ft.	.....	.....	1.5	1.4	1.4	.....	.....	.....
Cu. yds. backfill excav., per ft.	2.4	3.2	2.7	4.4	5.4	5.5	7.0	.....
Cu. yds. concrete excav., per ft.	0.395	0.349	0.150	.....	.....	.....	.....	.....
Cu. yds. stone masonry excavation, per ft.	1,800	1,250	.....	.....	.....	.....	.....	.....
Cu. yds. brick masonry excavation, per ft.	0.753	0.588	0.583	0.885	0.967	0.967	0.967	.....
Cost per lin. ft.:								
Excavatiton	$ 0.891	$ 0.377	$1.236	$ 1.412	$ 2.058	$ 1.630	$ 1.766	$ 1.787
Pumping—Draining	0.743	0.595	.....	.....	0.078	0.484	0.282	0.308
Concrete base	1.925	1.645	0.635	.....	.....	.....	.....	.....
Stone cradle	8.128	6.134	.....	.....	.....	.....	.....	.....
Brickwork	6.443	5.761	5.722	8.324	9.332	9.208	9.396	9.300
Backfilling	0.832	0.842	0.347	0.223	0.357	0.301	0.822	0.482
Engineering	0.715	0.663	0.916	0.572	0.500	0.463	0.420	0.460
Tools	0.424	0.320	0.381	0.150	0.097	0.100	0.140	0.112
Watchman, etc.	0.090	0.178	0.173	0.134	0.145	0.121	0.130	0.131
Total	$20.191	$16.515	$9.410	$10.815	$12.567	$12.292	$12.956	$12,580

Note.—Sec. 1 was built in filled ground containing city refuse. The original ground was about level with the invert, and had been filled with 2 to 5 ft. of refuse. The bottom of the trench was 2 to 4 ft. below the level of a river near by, so that there was much pumping. The backfill was largely hauled in with wagons.

averaged 11 ft. deep, and was timbered all along. No water was encountered. The sewer was three-ring brick.

Sec. 7 was similar in every way to Sec. 6, except that a loose sand overlaid the rock.

Sec. 8 was in gravel containing much water. The cut averaged 12½ ft. deep.

Sec. 9 was in fine, loose sand, heavily charged with water. The average cut was 14 ft. deep.

The concrete foundations were made 1 : 3 : 6 Portland cement and crushed, unscreened sandstone. The stone was estimated on a basis of 2,500 lbs. per cu. yd. Concrete was hand mixed and delivered in wheelbarrows. The average cost of 1,545 cu. yds. of concrete was as follows:

0.732 bbl. cement	$2.543
0.754 cu. yd. stone	1.409
0.424 cu. yd. sand	0.148
Water	0.007
Labor ($1.75 an 8-hr. day)	0.703
Total per cu. yd.	$4.810

The stone cradle was built of a soft sandstone which broke out square in the quarry so that little hammering was required in the trench. It was bought by the ton. Louisville (natural) cement, weighing 265 lbs. per bbl., was used in a 1 : 2 mortar. The average cost (not including engineering) of 6,438 cu. yds. of this stone cradle was as follows:

1.297 cu. yds. of rubble	$1.975
0.875 bbl. natural cement	1.261
0.305 cu. yd. sand	0.130
Water	0.005
Labor (masons, $3.60; laborers, $2.00, for 8 hrs.)	1.284
Total per cu. yd.	$4.655

The invert brick ring of Sec. 3 was laid in 1 : 3 Portland mortar, and the same mortar was used in plastering. On Secs. 1, 3 and 5 a 1 : 2½ Louisville mortar was used; and on Secs. 6, 7, 8 and 9, a 1 : 3 Louisville throughout.

The amount of cement per cubic yard of brickwork, by sections, was as follows: Sec. 10, 0.835 bbl.; Sec. 3, 1 bbl.; Sec. 5, 1.07 bbls.; Sec. 6, 0.87 bbl.; Sec. 7, 0.937 bbl.; Sec. 8, 0.99 bbl.; Sec. 9, 0.976 bbl. Assuming that the 1 : 2½ mortar required 2½ bbls. cement per cu. yd. of mortar, it would require 0.4 cu. yd. of mortar per cu. yd. of brick masonry when it took 1 bbl. of cement per cu yd. of brick masonry.

The number of brick per cubic yard ranged from 431 on Sec. 3 to 450 on Sec. 6. The average cost of 6,702 cu. yds. of brickwork on all sections was as follows, per cu. yd.:

439 brick	$4.584
0.92 bbl. cement	1.953
0.41 cu. yd. sand	0.198
Miscellaneous	0.229
Labor	2.384
Total per cu. yd.	$9.348

The labor cost ranged from $2 per cu. yd. on Secs. 1 and 3 to $2.95 on Sec. 9.

One foreman handled 18 bricklayers, divided into three gangs, the total number of his force, including helpers and laborers, being 80 men.

A neat form of steel centering was designed and used as follows: Light, 8-lb., dump-car rails were bent so as to form half-rings; the lower half-ring (or semi-circle) being bent with the

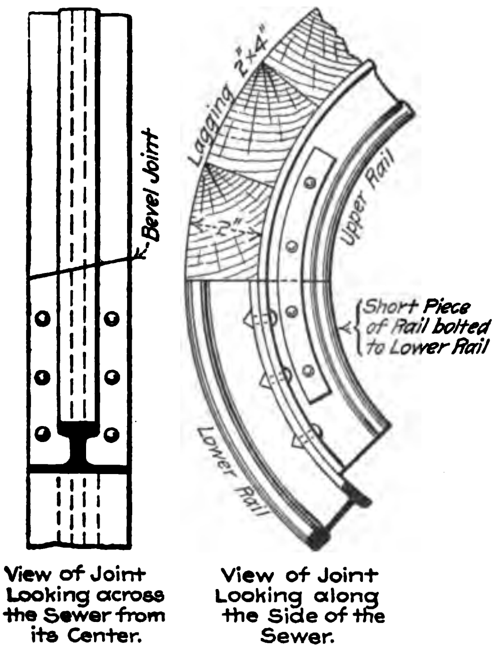


Fig. 4. Centers for Concrete Sewer.

head of the rail facing out, and the upper half-ring with its head facing in, as shown in Fig. 4. A short piece of rail was laid with its flange against the flange of the lower half-ring and riveted. One of these short pieces of rail was thus riveted at each end of the lower half-ring. Thus it was possible to butt the ends of the upper half-ring against these short pieces of rail riveted to the lower half-ring, and connect the two with fish-plates and bolts. In order to be able to "strike" (remove) these steel centers, a bevel-joint was made, as shown in the figure. This was done by sawing one end of the upper half-ring across on a bevel, and sawing a

similar bevel on the end of the short piece of rail against which it butted. After the fish-plate bolts were removed, a blow of a hammer would readily knock the two half-rings apart at the bevel-joint. It will be noted that the 2-in. lagging was laid upon the flange of the upper half-ring, no lagging being used on the lower half-ring, as the invert was built of brick.

To hold the lagging to the upper half-ring, it was found best to make little iron clips, three of which were fastened to the under-side of each 12-ft. stick of lagging, using two wood screws for each clip. The end of the clip slipped over the flange of the steel rail, but was not screwed or bolted to the rail, so that each stick of lagging was quickly removed by shoving it endwise. These steel centers or rings were placed 2 ft. 5 ins. apart, c. to c., so that 40 rings sufficed to set up centers for 96 ft. of sewer. Two men would take down, clean and set up 96 ft. of this centering in a day, making the cost of moving centers about 4 cts. per ft. of sewer. In building 8,290 ft. of sewers, three sets of steel centers and two sets of lagging were used, costing $775 for materials and labor of making, or 9.3 cts. per ft. of sewer, making a total cost of a little over 13 cts. per ft. of sewer for making and moving lagging and material. There were only three sets of rings because there were only three sizes of sewers, 70, 77 and 94-in.

Cost of an Egg Shaped Sewer, Springfield, Mass.*—The Worcester St. sewer, for which cost data are given below, was built at Springfield, Mass., during December, 1904, and January, 1905. It consists of 670 ft. of 1 ft. 10 in. by 2 ft. 9 in., egg-shaped brick sewer and two manholes. The sewer was laid in a gravel trench at an average depth of 9.8 ft., the grade being 6 in. per 100 ft. The loose character of the gravel necessitated tight sheeting of the trench all of the way.

The invert of the sewer was constructed of 8-in. brickwork, but the arch was of a single ring or 4-in. brick, plastered outside with 1 in. of cement mortar, Portland cement being used throughout.

At the time the work was done there was about 2½ ft. of frost in the ground, and consequently coke fires were built along the line of excavation in advance of the work. These fires required about $45 worth of wood and 536 bushels of coke at 11 cts. per bushel.

The excavation was done by pick and shovel, and the trench was backfilled as fast as the mason work was completed. The work was done by the city by day labor.

The wages paid per 8-hour day were as follows:

Foreman	$3.00
Bracers	2.00
Laborers	1.75
Teams	4.50
Masons	5.60
Mason tenders	2.40

Engineering-Contracting, Jan. 16, 1907.

The cost of the work is shown in the following tabulation:

Labor.	Per lin ft.
Excavating and refilling	$1.40
Sheeting	.23
Masons	.36
Tenders	.20
Total labor	$2.19
Material.	
Brick, $9.20 per M.	$ .79
Cement, at $1.60	.36
Manhole castings and steps	.02
Sheeting lumber, at $22.50	.05
Wood	.07
Coke (536 bu.)	.09
Profiles and centers	.01
Total materials	$1.39
Grand total	$3.58

The labor cost of constructing the brickwork was as follows:

	Per lin. ft.	Per cu. yd.
Masons, 42¾ days	$0.36	$2.14
Tenders, 57¾ days	.20	1.19
Total	$0.56	$3.33

On the work there were usually two masons and three tenders.

Cost of a 7-Ft. Brick Sewer, Gary, Ind.*—In trenching for a 7-ft. sewer through water soaked sand at Gary, Ind., the sand is being unwatered by driving well points and pumping. The method has enabled what promised to be a difficult task to be accomplished with comparative ease. Only a moderate amount of sheeting has been necessary and practically no caving has resulted.

The sand through which the work passes is very fine, such a sand as forms the dunes of Michigan and other states bordering Lake Michigan. When water soaked it takes a slope of about 1 on 15. At Gary this fine sand is water soaked to within a few feet of the surface; in places water covers the surface. So far as excavation work goes the material is to all intents and purposes a quicksand.

In brief, the method of work adopted is as follows: A wide shallow trench is excavated by a drag, scraper bucket excavator of the Page & Shnable type to about water level, say to a depth of 6 to 8 ft. Bleeding is then begun. A 4-in. pipe 132 ft. long in six 22-ft. sections it stretched along the center line of the sewer. On each side of this pipe about 3 ft. away is sunk a row of well points 2 ft. apart. These well points are 3 ft. long and are attached to 13-ft. pipes. The tops of the driven pipes are connected by hose to the 4-in. pipe line which has cross-valves for the purposes. A pump connects with the 4-in. pipe line and also with a 4-in. well point sunk vertically underneath. An extension of the 4-in. pipe line with strainer end also takes the surface water from a sump.

This battery of well points lowers the water so that a further excavation of 6 to 8 ft. can be made between sheet piling. A second

**Engineering-Contracting,* Aug. 5, 1908.

battery of well points is then sunk at this new level. In this battery, however, the points are sunk close to the sheeting and each row feeds into a separate 2-in. pipe along the trench. This battery lowers the water level enough to permit excavation to sub-grade, which is some 6-ft. below the bottom of the sheeting. The brick sewer is then built in the usual manner and the back-filling done by means of a derrick and Hayward clam shell bucket.

The diagram Fig. 4A shows the general plan of procedure described. In this description details have been neglected to prevent confusion; some of these details, however, require description.

Scraper Bucket Excavator Work.—The bucket is of 2 cu. yds. capacity and is operated on a 58-ft. boom with the usual cable and chain attachments. The sand being excavated is wet; that is, the voids are filled with water. The amount of excavation is 10 cu. yds. per running foot of trench, and the machine makes 60 ft. per day. This 60 ft. is not its capacity, but is the distance made daily by

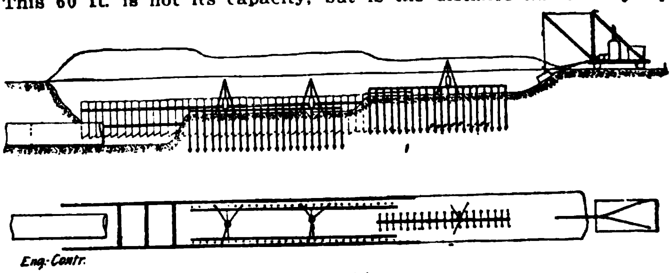


Fig. 4A.

all the work and the excavator is worked just enough to keep pace. The depth being excavated is also limited by water level.

The machine is mounted on rollers traveling on a track of timbers. One merit of the machine is that some of the excavated material can be dumped straight ahead in the path of the work so that it builds its own roadbed over the swamps in front. The machine is pulled ahead by simply lowering the bucket and letting it get a good bite in the ground ahead, then pulling on the digging cable.

The excavator is taking out about 400 cu. yds. per 9-hour day, with a gang of 1 engineer, 1 fireman and 4 laborers.

First Battery of Well Points.—Referring to Fig. 4A it will be seen that the first battery of well points occupies a narrow space along the center of the trench; this permits the sheeting to be driven outside of the well points. The well points are 2 ins. x 3 ft., and they are attached to 2-in. x 13-ft. pipes with ells at their tops. A 4-ft. length of wire lined hose is attached to each ell. These points are sunk vertically by jetting. Two men were timed in jetting. They used 1-in. jetting pipes with about 100 lbs. water pressure and sunk four points in one minute. This time did not

include making connections. In addition to the two rows of 2-in. points, a 4-in. point is sunk directly under the pump.

The well points are connected by the short hose lengths to a 4-in. horizontal suction pipe. Six 22-ft. sections of suction pipe are used with flanged joints. Each section has 11 cross-valves with double bushings for the hose connections. A gate valve near the end of each section permits the rear-sections to be removed and placed ahead as fast as the work progresses. An extension of the 4-in. suction pipe forward to a sump in the excavation being made by the scraper bucket handles the surface water.

The water is drawn from the suction pipe by an Emerson No. 3 pump with 5-in. suction and 4-in. discharge. The pump is hung to a chain fall from an A-frame mounted on rollers. It discharges into a tile drain alongside the trench; this drain leads back to the completed sewer discharging behind a temporary dam of bags of sand inside the sewer. Summarized, the first battery of well points is composed as follows:

1 No. 3 Emerson pump.
1 4-in. well point sunk below pump.
132 2-in. well points sunk in two rows.
1 4-in. suction pipe with extension to surface water sump.

Sheeting Trench.—The trench is sheeted 10 ft. wide, the sheeting being carried along so as to embrace about one section (the rearmost) of the first battery of well points. The sheeting is 2 x 8-in. x 12-ft. planks and is driven by mauls. Waling pieces and trench braces are placed as the excavation proceeds. This excavation is carried down about 6 ft. by shovelers and at this level the second battery of well points is placed. The sheeting is pulled as the back filling proceeds.

Second Battery of Well Points.—The second battery of well points consists of two rows like the first, but the rows are placed wide apart (close inside the sheeting on both sides) and each has a separate suction pipe. The suction pipes are 2 ins. in diameter and the well points are 1¼ ins. in diameter; the well points and pipes are 16 ft. long and when sunk they penetrate a couple feet or so below sub-grade and 6 ft. below the bottom of the sheeting. The suction points are made in sections with hose connections every two feet and gate valves at the ends.

Two pumps operate the second battery of well points; they are of the same size and make as that for the first battery and are suspended similarly. Each pump draws water from both rows of well points and also from a 4-in. well point sunk directly under the pump. This is accomplished by means of a four-way connection in the suction of each pump, about 1 ft. below the pump. From this connection 2-in. pipes branch right and left to connections with the 2-in. suction pipes and a third connection is made with the 4-in. well point. Operating in parallel the two pumps can, by means of the gate valves, concentrate their work on those portions of the battery of well points where especially large quantities of water are encountered or can pump from the whole system, also either

one of the pumps can be cut out. These pumps discharge into the same tile drain as the first pump.

The methods of advancing the second battery of well points is substantially the same as for the first; that is, the rear sections of suction pipe and well points are detached and placed in front. Generally the forward end of the second battery is kept far enough ahead to overlap the rear section of the first battery.

Excavation and Sewer Construction.—The deepening of the trench at the rear end of the second battery of well points is done by hand. So perfect is the drainage that it is found possible to excavate some 6 ft. deeper than the bottom of the sheeting, and to construct the brick sewer in the trench bottom with no more seepage than can be handled by a fourth Emerson pump, which takes water from a sump and discharges behind the temporary sand bag dam mentioned previously.

Backfilling.—The backfilling is done from the spoil bank. As fast as the sewer is completed, shovelers cover it with a layer of sand. The remainder of the backfilling is done by an 8¼ x 10-in. Lidgerwood engine and derrick operating a 1 cu. yd. Hayward clam shell. This machine puts in about 500 cu. yds. of backfill in 9 hours at a labor cost of about 4 cts. per cu. yd. figured as follows:

1 engineman at $5	$ 5.00
1 fireman at $3	3.00
3 laborers at $2	6.00
Fuel at $3.60 per ton	6.25
Total 500 cu. yds. at 4 cts.	$20.25

Sheeting and Bracing.—Two rows of 2 x 8-in. x 12-ft. sheeting 60 ft. long are driven, braced and pulled per 9-hour day with the following gang:

4 men setting braces at $2.25	$ 9.00
3 men driving sheeting at $2.50	7.50
4 men pulling sheeting at $2.50	10.00
1 carpenter at $3	3.00
Total	$29.50

This gives a cost of 24½ cts. per lineal foot of 12-ft. sheeting driven, braced and pulled, not including materials and superintendence, etc.

Pumping and Changing Piping.—The pumping is continuous day and night, but the jetting of well points and changing of piping is confined to the regular shift of 9 hours. The gang worked is as follows:

14 pipe line men at $2.25	$31.50
10 firemen (two shifts) at $3	30.00
2 foremen at $3	6.00
6 laborers at $2	12.00
Coal for 24 hours (estimated)	15.00
Total	$94.50

This gives a cost of $1.57 per lin. ft. of trench, not including superintendence, interest, depreciation, etc.

Trench Excavation.—The trench excavation, excluding scraper bucket works, runs about 300 cu. yds. per day, assuming 60 ft.

of 10.5 x 13 ft. trench per 9 hours. This work is done by 85 shovelers at $2 per day, and costs $170 ÷ 300 cu. yds. = 56.6 cts. per cu. yd.

Miscellaneous.—The cost of clearing the right of way amounts to $4 per day, 2 men at $2 being employed. There are 3 waterboys at $1, or a charge of $3 per day for waterboys.

Summary.—Summarizing we have the following costs for trench work complete and ready for sewer construction:

	Per day.	Per lin. ft.
Scraper excavator work (400 cu. yds.)	$ 22.25	$0.370
Shovel excavation (300 cu. yds.)	170.00	2.833
Sheeting and bracing (300 cu. yds.)	29.50	0.491
Pumping and pipe system (300 cu. yds.)	94.50	1.575
Backfilling (500 cu. yds.)	20.25	0.337
Miscellaneous (300 cu. yds.)	7.00	0.116
Total	$343.50	$5.722

Figured on a cubic yard basis these costs may be arranged as follows:

	Per cu. yd.
Scraper work, including clearing (400 cu. yds.)	$0.055
Trenching, pumping and sheeting (300 cu. yds.)	0.980
Backfilling (500 cu. yds.)	0.040

Brick Sewer Construction.—About 60 ft. of sewer are completed per 9-hour day. The labor and materials cost of this work runs about as follows:

Materials.		Per day.
30,000 brick at $6.50		$195.00
30 bbls. Portland cement at $1.75		52.50
30 bbls. Utica natural cement at $1		30.00
Total materials		$277.50
Labor.		
5 men mixing mortar	$2 50	$ 12.50
5 men carrying cement mortar	2.50	12.50
3 men lowering cement mortar	2.25	6.75
6 brick masons (5,000 brick each daily)	10.00	60.00
3 brick tenders	3.75	11.25
15 brick handlers (av.)	2.50	37.50
26 men on industrial railway	2.00	52.00
3 teamsters	2.50	7.50
3 teams	9.00	27.00
3 form setters	3.25	9.75
3 water boys	1.00	3.00
Total labor		$249.75
Total labor and materials		517.25

Assuming 500 brick per cubic yard of masonry, these figures give a cost of:

	Per cu yd.
Materials	$4.62
Labor	3.99
Total	$8.62

About 2 bbls. of cement were required per 1,000 brick laid, and the cost per 1,000 brick laid was $17.24.

The cost of superintendence on the work runs about $50 per day, and repairs, waste and depreciation aggregate about $40 per day.

In reviewing these figures it must be kept in mind that they omit a number of costs. For example, the cost of lumber for sheeting, runways, etc., and the cost of lumber and construction for centers are not included. Other lacking items will be noted by those familiar with such work. Though incomplete as noted the figures will, we believe, prove decidedly interesting in connection with the novel methods of work adopted.

[The costs are given in greater detail in the following paragraphs.]

Cost of a Brick Sewer in Water-Soaked Sand at Gary, Ind.*— In our issue of Aug. 5, 1908, we described in some detail the construction of a sewer in water soaked sand at Gary, Ind. The method adopted was to unwater the sand by bleeding—by sinking well points in the sand along the line of the sewer and drawing out the water with pumps. At the time this description was published the construction had not been completed nor the costs fully analyzed, so that the costs then published were only approximate. Since then the cost of the work has been worked out in considerable detail by City Engineer A. P. Melton and his assistant, Mr. E. M. Scheflow, and has been placed at our disposal by Mr. Melton.

The costs were compiled by keeping a force and time account of the work. The inspector kept the records on blanks prepared for the purpose and checked them with the books of the contractor's timekeeper. While some items of cost familiar to the contractor were not thus included, yet the figures given may be considered very close approximations.

The work comprised 4,258 ft. of brick sewer, ranging from 7 ft. circular section to 6 ft. 4 in. by 8 ft. 11 in. oval section, all with shells consisting of 2½ rings of brick. The soil was fine sand water soaked below a level about 22 ft. above subgrade; the water-soaked sand ran on a slope of about 1 on 15. The trench ranged from 18 to 30 ft. in depth. The method of excavation was fully described in our issue of Aug. 5. Briefly a preliminary wide cut was made some 5 to 15 ft. deep with machines, then well points were sunk and the ground drained, after which excavation proceeded by hand between sheeting. The masonry work and backfilling followed. The cost of construction was divided into the following items: Machine excavation, sheeting, pumping, hauling materials, sewer building, backfilling, materials and organization.

Machine Excavation.—The preliminary wide shallow cut only was excavated by machine. A ¾ cu. yd. Hayward orange peel bucket operated by a 25-hp. engine was used for the first 1,900 ft. and took out 21,250 cu. yds. at the following cost:

Item.	Total.	Per cu yd.
Engineer, 56 days, at $6....	$ 336.00	$0.0153
Fireman, 56 days, at $3.50...	196.00	0.0092
Laborers, 255 days, at $1.75.	446.25	0.0210
Coal, 56 shifts, at $5.........	280.00	0.0131
Total	$1,258.25	$0.0586

At this point the orange peel was removed to the rear to work on backfilling and a Page & Schnable drag scraper excavator was

*Engineering-Contracting, Oct. 7, 1908.

substituted. This machine had a 2 cu. yd. bucket and a 40-hp. engine; this engine was found to be too weak and was used only until a larger one could be secured. Another objection to the first arrangement was that two men were required to operate the bucket, one at the hoist and one at the swing engine. With the machine as first equipped and operated 15,300 cu. yds. of material were excavated at the following cost:

Item.	Total.	Per cu. yd.
Engineer, 31 days, at $6	$186.00	$0.0122
Fireman, 31 days, at $3.50	108.50	0.0071
Engineer, 31 days, at $3	93.00	0.0060
Laborers, 118 days, at $1.75	206.50	0.0138
Coal, 31 shifts, at $5	155.00	0.0101
Total	$749.00	$0.0492

The 40-hp. engine was replaced by one of 60 hp., so arranged that one man operated both hoist and swinging engine. With the remodeled outfit 11,000 cu. yds. of material were excavated at the following cost:

Item.	Total.	Per cu. yd.
Engineer, 21 days, at $6	$126.00	$0.0114
Fireman, 21 days, at $3.50	73.50	0.0067
Laborers, 84 days, at $1.75	147.00	0.0133
Coal, 21 shifts, at $5	105.00	0.0095
Total	$451.50	$0.0409

It will be seen that the change of the engines reduced the cost per cubic yard by the amount of the wages of one engineer; the saving was 0.83 cts. per cu. yd. Summarizing we have a cost of $2,488.75 for excavating 47,550 cu. yds., or of $0.0523 per cu. yd. For the 4,258 ft. of sewer the cost was 57.9 cts. per lin. ft.

Hand Excavation.—The bottom 13 ft. in depth of the trench was excavated by hand between sheeting; the width of the excavation was approximately 10 ft. The cost of the work was as follows:

Item.	Total.	Per cu. yd.
Laborers, 6,441 days, at $2	$12,882.50	$0.5413
Foreman, 84 days, at $3	522.00	0.0232
Total	$13,434.00	$0.5645

The total amount of hand excavation was 23,800 cu. yds.

Sheeting.—The sheeting consisted of vertical 2 x 8-in. by 12-ft. planks held by two pairs of 6 x 8-in. waling pieces and 9-ft. cross braces spaced 8 ft. apart. In cases of very wet trench a third row of waling and braces was put in; occasionally, also, horizontal sheeting was used in the bottom. The cost of driving the sheeting and placing the bracing and also of pulling it was as follows:

Placing.	Total.	Per lin. ft.
Laborers, 882 days, at $2	$1,764	$0.4142
Foreman, 80 days, at $3.50	280	0.0658
Carpenters, 50 days, at $3	150	0.0351
Total	$2,194	$0.5151
Pulling:		
Laborers, 242 days, at $2	$ 484	$0.1136
Grand total	$2,678	$0.6287

Pumping.—The item of pumping comprises all the work of sinking and shifting the well points and pipe line and the removal of the backwater in the finished part of the sewer. Three Emerson pumps took water from the well points, a fourth handled the backwater and a duplex pump furnished water for boilers, mixing mortar, jetting, etc. The cost was as follows:

Item.	Total.	Per lin. ft.
Laborers, 542 days, at $1.75..	$ 948.50	$0.2227
Pipe line men, 958 days, at $2.50	2,395.00	0.5625
Total for pipe work	$3,343.50	$0.7852
Coal, 100 days, at $15	$1,500.00	$0.3499
Firemen, 855 days, at $3.50	2,992.50	0.7025
Total for pumping	$4,492.50	$1.0524
Grand total	$7,836.00	$1.8376

Pumping costs and pipe line costs have been separated, since the first is a continuous expense which does not vary from day to day, and the second cost is operative only when construction is actually going on.

Hauling Brick and Other Materials.—The materials were hauled 1,500 ft. in steel dump cars running on portable track; the cars were pushed by hand. Coal, lumber, supplies, etc., purchased from local dealers, were hauled by team. The cost of hauling was as follows:

Item.	Total.	Per lin. ft.
Laborers, 1,219 days, at $2	$2,438	$0.5725
Foreman, 80 days, at $3.50	280	0.0657
Teams and drivers, 180 days, at $5.50	990	0.2322
Total	$3,708	$0.8704

Sewer Construction.—The construction of the 4,258 ft. brick sewer was as follows:

Item.	Total.	Per lin. ft.
Laborers, 1,506 days, at $2..	$ 3,012.00	$0.7073
Carpenters, 50 days, at $3..	150.00	0.0351
Form setters, 225 days, at $3.75	843.75	0.1981
Bricklayers, 471 days, at $10	4,710.00	1.1061
Scaffold men, 236 days, at $2.75	649.00	0.1524
Brick tenders, 236 days, at $3.75	885.00	0.2076
Mortar mixers, 387 days, at $2.25	860.75	0.2021
Total	$11,110.50	$2.6087

As noted further on, the cost of brick and cement for the job was $14,436.50, or $2.384 per foot of sewer, making the total cost for labor and materials $4.993 per lin. ft. Since there were 520 bricks per lin. ft. of sewer, the cost per cubic yard of the brickwork was approximately the same as the cost per lineal foot. The bricklayers averaged 4,710 bricks per man per 9-hr. day. Two barrels of cement were used per 1,000 bricks.

Backfilling.—Enough backfilling was done by hand to cover the sewer and to permit the sheeting to be pulled; the remainder was done with the clam-shell excavator first used for preliminary trenching. The cost of backfilling by hand was as follows:

Item.	Total.	Per lin. ft.
Laborers, 378 days, at $2	$756	$0.18

The cost of backfilling by machine was as follows:

Item.	Total.	Per lin. ft.
Laborers, 307 days, at $1.75	$537.25	$0.1261
Engineers, 93 days, at $6	558.00	0.1287
Firemen, 93 days, at $3.50	325.50	0.0764
Coal, 93 shifts, at $5	465.00	0.1092
Total	$1,885.75	$0.4404

Materials.—The cost of the materials used in the job was as follows:

Item.	Total.	Per lin. ft.
2,221,000 brick, at $5	$11,105.00	$2.6080
Utica cement, 6,663 sacks, at 20 cts.	1,332.60	0.3106
Universal cement, 6,663 sacks, at 30 cts.	1,998.90	0.4694
30 M ft. B. M. lumber, at $20	600.00	0.1409
Total	$15,036.50	$3.5289

Superintendence and General Expenses.—The costs of superintendence and general expenses were as follows:

Superintendence.	Total.	Per lin. ft.
Superintendent, 4 mos., at $150	$ 600	$0.1409
Gen'l foreman, 4 mos., at $125	500	0.1174
Master mechanic, 4 mos., at $200	800	0.1855
Timekeeper, 3 mos., at $60	180	0.0422
Team, 100 days, at $4	400	0.0927
Total	$2,480	$0.5787
General expenses.		
Waterboys, 220 days, at $1.50	$ 330	$0.0775
Clearing right of way, 60 days at $150	90	0.0211
Total	$ 420	$0.0986

Summarizing we have the cost per lineal foot of sewer as follows:

Item.	Per lin ft.
Excavation by machine	$ 0.58
Excavation by hand	3.15
Sheeting	0.63
Hauling brick and other materials	0.87
Pumping	1.84
Laying brick sewer	2.61
Backfilling by hand	0.18
Backfilling by machine	0.44
Materials	3.53
Superintendence and general	0.68
Depreciation, repairs, setting up machines	1.50
Making 3 railway crossings ($2,500)	0.58
Total	$16.59

The work was begun on April 2 and was completed on Aug. 5,

1908, during which time only 11 days were lost by the bricklayers.

Cost of a 66-in. Brick Sewer at Gary, Ind.*—The methods and cost of constructing a brick sewer of oval section, 6 ft. 2 ins. x 8 ft. 11 ins. in size, at Gary, Ind., were published in our issues of Aug. 5 and Oct. 7, 1908. This oval section changes to a circular section 66 ins. in diameter and then to a circular section 60 ins. in diameter, which continue the sewer inland. The costs of the circular sections, 4,062 ft. long, have recently been compiled from inspectors' and timekeepers' reports by City Engineer A. P. Melton and Assistant Engineer E. M. Scheflow and are given us for publication.

The land through which the sewer passes consists of alternating ridges and marshes differing in elevation about 10 ft. The trench, therefore, varied in depth between a maximum of 24 ft. and a minimum of 14 ft., and averaged 17 ft. in depth. The material trenched was a fine sand saturated with water to a height of 13 to 14 ft. above the bottom of the trench. The water-soaked sand was very unstable, taking a slope of about 1 on 15 when unconfined.

The method of excavation was to take out a wide cut between natural banks to about waterline level, then to drive sheeting and excavate between it to subgrade. To permit excavation between sheeting the sand was freed of its water to below sub-grade level by sinking batteries of well points and pumping. Full details of the bleeding plant were given in our issue of Aug. 5, 1908. The wide surface cut was made with a drag bucket excavator, with two objects, to get a wide working space, and to reduce the depth of sheeting.

Construction was begun Aug. 1 and finished Oct. 1, 1908. Laborers on excavation sheeting, pumping, etc., worked a 10-hour day; tenders, cement mixers and helpers to bricklayers worked a 9-hour day; bricklayers worked an 8-hour day; firemen on pumps worked in 12-hour shifts, and excavating machine crews worked a 9-hour day. The costs of the various items of the work were as follows:

Drag Bucket Excavator Work.—The preliminary cut was about 30 ft. wide and from 4 to 10 ft. deep; there were 33,350 cu. yds. of excavation for the 4,062 ft. of sewer or about 8.21 cu. yds. per lin. ft. The excavator worked 83.5 shifts and so averaged nearly 400 cu. yds. per shift of 9 hours. The cost of operating the excavator was as follows:

Item.	Per 9-hr. shift.
1 engineman, at $6	$ 6.00
1 fireman, at $3.50	3.50
4 laborers, at $2	8.00
Coal (estimated)	5.00
Oil, repairs, etc.	2.00
Total	$24.50

This gives a cost of 6.1 cts. per cu. yd. of excavation and of 50.3 cts. per lin. ft. of sewer.

**Engineering-Contracting,* Jan. 27, 1909.

Excavation by Hand.—The excavation between sheeting, approximately 8½x10 ft., was done by hand, scaffolding the material from 3 to 5 times and an average of 4 times. The cost of the work was as follows:

Item.	Total.
Foreman, 51 days, at $3.25	$ 165.75
Laborers, 2,184 days, at $2.25	4,914.00
Total	$5,079.75

This gives a cost of 39.4 cts. per cu. yd., and of $1.25 per lin. ft. of sewer.

Pumping.—The pumping plant consisted of 3 No. 8 Emerson pumps drawing from the well points; 1 No. 2 Emerson pump taking water from the pools formed behind the drag bucket excavator; 1 duplex pump for boiler feed, jetting points, wetting brick, etc., and 4 30-hp. horizontal boilers mounted on wheels. This plant worked continuously. The cost of operation was as follows:

Item.	Total.
Laborers, 464 days, at $2	$ 928.00
Fireman, 439 days, at $3.50	1,536.50
Pipe linemen, 1,238 days, at $2.50	3,094.00
Foreman, 27 days, at $3.50	94.50
Coal, 60 days, at $15 (estimated)	900.00
Total	$6,553.00

This gives a cost per lineal foot of sewer of $1.61 for pumping. Charged entirely against the excavation between sheeting which was closely 12,893 cu. yds., the cost of pumping per cubic yard of excavation was 50.8 cts.

Sheeting.—The sheeting consisted of 2x8 in. x. 12 ft. plank driven close on each side of the trench. This sheeting was braced apart by two 6x8 in. walling pieces set 3 ft. apart vertically and 6x8 in. x 8½ ft. cross-braces spaced 8 ft. apart along trench. The cost for sinking, bracing, pulling and bringing forward was as follows:

Item.	Total.
Labor, placing and driving, 392 days, at $2.25	$ 882.00
Labor, pulling and bringing ahead, 182 days, at $2.25	409.50
Foreman, 27 days, at $3.50	94.50
Carpenter, 36 days, at $3	108.00
Total	$1,494.00

This gives a cost for sheeting of 36.8 cts. per lin. ft. of trench and of 11.6 cts. per cu. yd. of excavation between sheeting. There were about 73 ft. B. M. of sheeting and bracing per lineal foot of trench, so that the cost per M. ft. B. M. was practically $5 for labor placing, pulling, etc.

Laying Brick Sewer.—The sewer was built of two rings of brick. The invert was built in 24-ft. sections. Wooden centers with lagging 16 ft. long were used in laying the arch and 2 men knocked the

centers down, brought them forward and re-erected them as fast as 6 bricklayers could work. The cost of laying was as follows:

Item.	Total.
Bricklayers, 223 days, at $10	$2,230.00
Tenders, 112 days, at $3.75	420.00
Scaffoldmen, 111 days, at $2.75	305.25
Mortar mixers, 225 days, at $2.50	562.50
Form setters, 100 days, at $3.75	375.00
Laborers, 715 days, at $2	1,430.00
Carpenter, 18 days, at $3	54.00
Total	$5,376.75

This gives a cost of $1.32 per lin. ft. of sewer and of $5.28 per 1,000 bricks laid.

Backfilling.—The backfilling to a height of 2 ft. above the brickwork was done by hand, and for the remainder of the height by a 1-cu. yd. Hayward clam shell excavator. The backfilling by hand called for 277 days' labor at $2 and cost, therefore, $554 or 13.6 cts. per lin. ft. of sewer. The cost of the clam-shell excavator work was as follows:

Item.	Per shift.
1 engineer, at $6	$ 6.00
1 fireman, at $3	3.00
3 laborers, at $2	6.00
Coal (estimated)	5.00
Oil, repairs, etc.	2.00
Total	$22.00

There were 55 shifts worked giving a total cost of $1,210. In addition the drag bucket excavator was worked backfilling for 18 shifts at $24.50 making a total of $441. Lumping the work of both machines, the cost of backfilling was 40.6 cts. per lin. ft. of sewer and 6.8 cts. per cu. yd.

Materials.—The cost of materials was as follows:

Item.	Total.
1,018,000 brick, at $5 per M	$5,090.00
3,054 bags Utica cement, at 20 cts.	610.80
3,054 bags Universal cement, at 35 cts.	1,065.90
Lumber (estimated)	600.00
Total	$7,369.70

This is a cost of $1.81 per lin. ft. of sewer.

Hauling Materials.—For about 3,000 ft. of the work all materials were hauled from the railway siding in 2 cu. yd. steel dump cars running on narrow gage track. The average haul was 1,700 ft. For the remainder of the work the hauling was done with teams; brick were hauled by subcontract for 70 cts. per M. Two teams were also employed throughout the work to haul supplies from local dealers and to haul coal to the excavators when they were beyond reach of the contractors' railway. The cost of hauling was as follows:

Item.	Total.
Laborers, 767 days, at $2	$1,534.00
Foreman, 52 days, at $3.50	182.00
Brick, hauled by team at 70 cts. per M.	194.60
Teams, 100 days, at $5.50	550.00
Total	$2,460.00

The cost of hauling was thus 60.7 cts. per lin. ft. of sewer.

Superintendence and General Expenses.—The costs under these items comprised the following:

Item.	Total.
Superintendent, 2 months, at $150......	$ 300.00
General foreman, 2 months, at $150....	300.00
Master mechanic, 1 month, at $200......	200.00
Clearing right of way.................	80.00
Waterboys, 160 days, at $1.50..........	240.00
Handy teams, 52 days, at $3...........	156.00
Total	$1,226.00

This gives a cost of 30 cts. per lin. ft. of sewer.

Summary.—Summarizing the costs of the work per lineal foot of sewer we have:

Item.	Per lin. ft.
Drag bucket excavation..................	$0.503
Hand excavation	1.250
Pumping	1.610
Sheeting	0.368
Laying sewer	1.320
Backfilling by hand.....................	0.136
Backfilling by machine..................	0.406
Materials	1.810
Hauling materials	0.607
Superintendence and general..............	0.300
Depreciation of plant, repairs, etc. (estimated)	1.500
Total	$9.810

Cost of Rock Excavation for Sewer Trenches in St. Louis.—The following data were published in *Engineering-Contracting,* May 30, 1906: The excavation of sewer trenches in South Benton street, Sewer District No. 6, St. Louis, was mostly in solid rock, of a limestone formation usual to the vicinity. The work was done by contract, and the actual cost of the work is given below.

The rock is a limestone lying in horizontal ledges or strata, 1 ft. to 3 ft. thick. The top 4 ft. or 5 ft. of rock is more or less rotten and seamy, easily shot and sledged to pieces. Below this top rock it is hard and difficult to break up.

Dirt seams run through it all, at times causing the ledge to break out back under the sides of the trench, requiring considerably more excavation than is estimated and paid for under the specifications. An estimate of this extra excavation is about 20% more than is paid for. The specifications stated that when solid rock was encountered in laying pipe sewers, the solid rock was to be excavated 6 ins. below the flow line for all pipes of 18 ins. or less in diameter, and 9 ins. below the flow line for pipes of greater diameter than 18 ins. The trench was then to be filled with sufficient earth, well rammed, to form a foundation upon which the pipe should be laid. Payment for the work was made as follows: Class "A," (Earth), Class "B" (Loose Rock), Class "C" (Solid Rock), and quicksand excavation for pipe sewers was paid for at the prices bid for Class "A," Class "B," Class "C" and quicksand excavation, respectively, and was estimated for a width 12 ins. greater than the inside di-

ameter of the pipe, for all pipe 18 in. or less in diameter and 15 in. for pipes of greater inside diameter than 18 ins.

To quarry the top rock, the drill holes were staggered, spaced about 4 ft. apart along the trench and about 6 ins. from the sides of the required width of trench. See Fig. 5. In the lower and harder rock, the spacing of drill roles was 2½ ft. but similarly staggered. If any rock projected too far out, it was sledged or shot off by light shots.

To break up a ledge or strata, the drill holes in the top rock were driven about half way through the ledge while for the lower rock they were driven ⅔ to ¾ the thickness of ledge. Hand drills, 1¾-in. bit, were used, one man to a drill, and about 10 lin. ft. of hole was drilled per 8 hours' work. The shots were about one stick of 60% dynamite per foot in depth of drill hole.

The costs given here do not include insurance, collection of special tax bills, tools, and office expenses. The blacksmith bill was $355, or 20 cts. per cu. yd.; the powder bill $689.76, for about 4,300 lbs. of dynamite; the wages of foremen were $5.00, quarrymen $3.00,

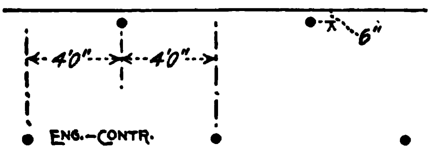


Fig. 5. Spacing of Drill Holes.

and a few laborers $2.00 per 8-hour day. The total amount of rock paid for was 1,683 cu. yds. The cost of dynamite was, therefore, $0.40 per cu. yd., and amount was 2¼ lbs. per cu. yd. On the supposition of 1-5 more rock actually handled than allowed in the estimates, the dynamite is $0.34 per cu. yd., or 2 lbs. per cu. yd. The average amount of rock for an 8-hour day per quarryman was 0.96 cu. yd.

The following tables are based upon measurements and quantities estimated and paid for under the specifications. The average costs are derived from this estimate and the expense account on the whole or actual excavation.

370 lin. ft., 21-in. sewer; average depth in solid rock, 14 ft.:

Foreman, 67 days, at $5	$ 335
Quarryman, 700 days, at $3	2,100
Laborer, 73 days, at $2	146
Total, 600 cu. yds., at $4.30	$2,581

287 lin. ft., 18-in. sewer; average depth in solid rock, 12 ft.:

Foreman, 54 days, at $5	$ 270
Quarryman, 343 days, at $3	1,029
Laborer, 53 days, at $2	106
Total, 317 cu. yds., at $4.43	$1,405

314 lin. ft., 18-in. sewer; average depth in solid rock, 13 ft.:

Foreman, 65 days, at $5	$ 320
Quarryman, 350 days, at $3	1,050
Laborer, 80½ days, at $2	161
Total, 380 cu. yds., at $4.04	$1,536

222 lin. ft., 15-in. sewer; average depth in solid rock, 11 ft.:

Foreman, 36 days, at $5	$180
Quarryman, 215 days, at $3	645
Laborer, 40 days, at $2	80
Total, 206 cu. yds., at $4.39	$905

251 lin. ft., 15-in. sewer; average depth in solid rock, 8 ft.:

Foreman, 32 days, at $5	$160
Quarryman, 129 days, at $3	387
Laborer, 60 days, at $2	120
Total, 180 cu. yds., at $3.70	$667

The average cost of the rock excavation was as follows:

	Per cu. yd.
Foreman and labor	$4.20
Dynamite	0.40
Blacksmith	0.20
Total	$4.80

On the estimate of 1-5 more actually excavated than allowed for the average cost of rock excavation was as follows:

	Per cu. yd.
Foreman and labor	$3.50
Dynamite	0.34
Blacksmith	0.16
Total (actual excavation)	$4.00

The cost of excavation of earth and loose rock was $0.50 and $1.40 per cu. yd., respectively. The cost of backfilling was $0.15 per cu. yd. of excavation.

For the information in this article we are indebted to Mr. Curtis Hill, Civil Engineer of the Sewer Department, St. Louis, Mo.

Cost of Pipe and Brick Sewers, St. Louis.—Mr. Curtis Hill gives the following data, which are averages of work done by contract during three years, April, 1901, to April, 1904. The work consisted in building 40 miles of vitrified pipe sewers, 12 to 24 ins. diam., and 13 miles of egg-shaped (18 x 27-in. to 48 x 60-in.) and circular (60 to 108-in.) sewers. The egg-shaped sewers were 9 ins. thick; the circular sewers were 13 ins. thick. The excavation was, for the most part, in stiff clay, only a small amount of quicksand occurring. Trench excavators were not very successful, because the "joint clay" caved in if not well braced as fast as excavated. The Chicago Sewer Excavator, however, made the best records made with trench excavators. Potter trench machines were largely used for the smaller trenches, and cableways for the larger trenches. The Potter machine consists of a movable trestle, and a bucket car that rides on tracks on top of the trestle bents. This car is moved back and forth by a stationary hoisting engine, which also hoists the buckets. The legs of the trestle span the trench and are provided with wheels that rest on rails.

The following table gives the actual average cost to the contractors, including foremen and superintendence, but not including interest and depreciation of plant, insurance of men, and office expenses.

COST OF PIPE AND BRICK SEWERS, ST. LOUIS.

Brick Sewers.	Earth Excavation. Cut in feet to sub-grade.	Cu. yds. per laborer per hour	Cost per cu. yd.	Brick Masonry. Cu. yd. per mason per hour.	Cost of labor and mason per cu. yd.	Cost of material per cu. yd.	Total cost per cu. yd.
12½′ x 15′*....	30	...	.....	1.18	$1.71	$6.13	$7.84
9′ circular†.....	26	1.0	$0.36	1.00	1.87	6.13	8.00
6′ circular†.....	17	0.8	0.40	0.97	1.75	6.30	8.05
5′ circular†.....	16	0.8	0.40	0.95	1.80	6.30	8.10
2′ x 3′‡........	11	...	.....	0.80	2.40	6.10	8.50

* Method of excavation was steam shovel followed by a cableway. The lumber bracing cost $3.60 per running foot of sewer.
† Potter trench machine used.
‡ No trench machine used.

The "cu. yds. per laborer per hr." means the number of cubic yards excavated and loaded into buckets by each laborer actually engaged in digging. The average of all the work, including pipe sewers, was about 9 cu. yds. excavated per man per 10-hr. day.

On pipe sewer trenches, where no machinery was used, the cost of earth excavating was as follows:

Size of pipe, ins.	Depth in ft.	Cost per cu. yd.
24	15	$0.50
21	16	0.50
21	7	0.35
18	8	0.35
15	16	0.55

It cost 90 cts. per cu. yd. to excavate loose rock in the trenches 15 and 16 ft. deep; and $3.80 per cu. yd. to excavate solid rock.

"Four men, the bottomman and his helper, with two men handling and lowering the pipe, laid 21-in. and 24-in. pipe at the rate of sixteen lineal feet per hour, at a cost of 6 cts. per lin. ft. Three men will lay the same amount of 15-in. or 18-in. pipe in the same time. Including the material for jointing, the cost of laying pipe is 10 cts. per lin. ft.

"A good sewer brick mason will lay from 400 to 500 bricks per hr. There is one case where four masons, working on a 6½-ft. brick sewer, each averaged 600 bricks per hr., and kept it up for several days, but this is far above the average."

The average contract prices for the three years (1901-4) was as follows:

12-in. pipe, per lineal foot..........................	$ 0.45
15-in. pipe, per lineal foot..........................	0.55
18-in. pipe, per lineal foot..........................	0.80
21-in. pipe, per lineal foot..........................	1.00
24-in. pipe, per lineal foot..........................	1.60

Pipe junctions, extra, each	1.50
Slants for brick sewers, each	0.65
Earth excavation, per cubic yard	0.55
Loose rock excavation, per cubic yard	1.60
Solid rock excavation, per cubic yard	4.00
Concrete, per cubic yard	6.50
Brick masonry, per cubic yard	9.40
Vitrified brick masonry, per cubic yard	12.20

It will be noted that the excavation was paid for as a separate item, and not included with the pipe or brick.

Mr. Hill informs me that on a recently completed brick sewer, requiring 287 days to build, two Potter machines and a cableway were used. There were 49,918 cu. yds. of Class "A" excavation (earth), 6,629 cu. yds. of Class "B" (loose rock), and 33 cu. yds. of Class "C" (solid rock). There were 2,303 lin. ft. of 9-ft. sewer, 3,240 lin. ft. of 8-ft. sewer, 254 lin. ft. of 7-ft. sewer, 1,607 lin. ft. of 5½-ft. sewer, and 1,203 lin. ft. of 4 x 5-ft. sewer. These required 8,177 cu. yds. of hard brick masonry and 723 cu. yds. of vitrified brick masonry. The excavation ("A," "B" and "C") cost 68 cts. per cu. yd., of which 11½ cts. was the cost of the trench machines. The total cost of this trench excavation (56,580 cu. yds.), including labor of bracing and backfilling, was as follows:

Foreman, 6,400 hours, at 50 cts.	$ 3,200.00
Laborer, 87,000 hours, at 22½ cts.	19.575.00
Bottom-man (pipe layer), 6,360 hours, at 30 cts.	1,908.00
Waterboy, 3,800 hours, at 15 cts.	570.00
Team, 10,450 hours, at 50 cts.	5,225.00
Watchman, 4,800 hours, at 25 cts.	1,200.00
Machine, 4,400 hours, at $1.50	6,600.00
Total, 56,580 cu. yds., at $0.68	$38,278.00

Most of the trenches require bracing, the timber for which costs 2 cts. to 10 cts. per cu. yd. of excavation, which is not included in the above. Yellow pine costs $18 per M.

The wages of foremen, waterboys and watchmen are all charged against excavation, and no part against masonry.

The cost of laying the brick masonry was as follows:

Masons, 9,400 hrs., at 75 cts.	$ 7,050.00
Helpers, 1,400 hrs., at 25 cts.	3,500.00
Mortarmen, 10,750 hrs., at 27½ cts.	2,956.25
Total for 8,900 cu. yds., at $1.52	$13,506.25

The masons averaged 422 bricks per hr., or 3,376 bricks per 8-hr. day.

Cost of a Brick Sewer at St. Louis, Including Tunneling in Earth and in Rock.—The following data were published in *Engineering-Contracting*, July 10, 1907.

The 13th street sewer in St. Louis, Mo., was designed to give deep drainage in a down town district, where the street is narrow, the traffic heavy, and the ground well filled with pipes and conduits. Owing to these conditions, the plans were made and contract let for tunneling the entire sewer. The sewer is brick, 30-in. x 42-in. diameter and 1,458 ft. in length.

Taking a mean length of earth and rock, there were 630 ft. of earth and 828 ft. of solid rock tunnel. Five shafts were used in the earth section and ten in the rock.

The work was done by the Myers Construction Co. of St. Louis during the winter of 1906-1907, in 190 days, including Sundays and holidays.

The contract included the excavation of 1,156 cu. yds. of earth

COST OF A WEEK'S SEWER WORK ON FOUR JOBS.
(Two Brick and Two Pipe Sewers)

Kind of Trench Mach.		Potter		Potter		Carson		None	
	Wages per hour	Job No. 1		Job No. 2		Job No. 3		Job No. 4	
		Hrs.	Wages	Hrs.	Wages	Hrs.	Wages	Hrs.	Wages
Foreman....	$0.50	54	$27.00	54	$27.00	54	$27.00	9	$4.50
Laborer.....	.22½	1,089	245.02	1,000	225.00	640	144.00	126	28.35
Bottom man.	.30	50	15.00	47	14.10	54	16.20	9	2.70
Water boy...	.15	54	8.10	54	8.10	54	8.10	9	1.35
Team.......	.50	54	27.00	......	....	......	....	......	....
Watchman..	.25	63	15.75	......	....	54	13.50	......	....
*Machine....	1.50	64	81.00	54	81.00	54	81.00	......	....
Total for excavation.		$418.87		$355.20		$289.20		$36.90	
Total cu. yds. "		980		600		407		120	
Cubic yards per hour per man..........		0.9		0.6		0.64		0.95	
Cost per cubic yard..		$0.43		$0.60		$0.71		$0.31	
Depth of trench, ft..		19½		23		18		Shallow	
Kind of soil.........		Sandy		Stiff earth and clay		Stiff earth, fire clay and 30% loose rk.		Black loam	
Size of sewer.......		3x4 ft.		2½ x 3½ ft.		18-in. pipe		21-in. pipe	
Length of sewer, ft..		300		154		244		108	
Brick Mason.	$0.75	104	$78.00	68	$51.00				
Helper......	.25	104	26.00	84	21.00				
Mortarman..	.27½	104	28.60	84	23.10				
Total................			$132.60	......	$95.10	4½ lin. ft. of pipe (double strength) laid per hour per bottom man (or pipe layer), whose wages are 30 cents per hour		12 lin. ft. of pipe per hour per bottom man. Trench shallow, no scaffolding or bracing	
Cu. yds. brick masonry...		112		61					
Cu. yds. per mason, per hr..		1.08		0.90					
Cost of labor per cubic yard masonry..............		$1.20		$1.56					
450 brick at $8.25 M........		3.71		3.71					
0.7 bbl. cement (1-3 mort.) at $1.50....................		1.05		1.05					
0.2 cu. yds. sand, at $1.10...		0.22		0.22					
Total per cubic yard brick masonry..............		$6.18		$6.54					

* A trench machine is rented for $125 per month, and burns 15 bushels of coal per 9-hour day. When the rental and fuel costs are added to the wages of engineman and fireman, the total cost is $1.50 per hour.

and 880 cu. yds. of rock, and the construction of 770 cu. yds. of brick masonry. The work was paid for on the unit basis and all work done was measured up and paid for.

The earth was a plastic clay, which would drop out in the arch following the shovel. In this way extra work over the arch (over and above the regular 9-in. brick work) averaged 8 ins. In the

rock tunnel, the average was 7 ins. over the arch and 6 ins. on the lower quarter haunches of the invert. These spaces were filled solid with brick masonry.

In the earth section, a small opening was driven 4 ft. to 6 ft. in length, and braced with a crown plank and short upright supports. As this was enlarged, other crown planks were inserted, replacing the shorter supports with longer ones. The masonry was then built in the section, removing the timber supports as the masonry progressed. Material for the next section was passed through the finished one.

The rock was a stratified limestone, irregular and gnarly. It varied in hardness, in some places to a flinty appearance. The blasting was done in batteries of three shots, the first in the upper, or arch, portion of the heading. When this broken rock had been removed, the same process was repeated on the lower, or invert, section. Holes were driven to a depth of about 2 ft. and loaded with from ¾ to 1½ sticks of 50 per cent dynamite, the size of stick depending upon the indicated hardness and position of the rock.

The cost of the work was as follows:

Earth excavation:	Per cu. yd.
Foreman, 520 hrs., at $0.50	$0.225
Bottommen, 1,320 hrs., at $0.50	.571
Laborers, 7,500 hrs., at $0.30	1.946
Carpenter, 830 hrs., at $0.50	.359
Labor, timbering, 620 hrs., at $0.30	.161
Timber, 22 M ft., at $20	.381
Watchman, 520 hrs., at .017½	.079
Waste, 585 loads, at $1	.506
Total	$4.228

The earth excavation amounted to 1,156 cu. yds. and each laborer averaged .154 cu. yd. per hour.

Rock excavation:	Per cu. yd.
Foreman, 1,000 hrs., at $0.50	$0.568
Bottommen, 2,600 hrs., at $0.50	1.477
Laborers, 9,980 hrs., at $0.30	3.402
Engineer, 1,600 hrs., at $0.50	.909
Blacksmith	.070
Watchman, 1,600 hrs., at $0.17½	.318
Dynamite, 4,000 lbs., at $0.15	.682
Caps and fuse	.030
Waste, 445 loads, at $1	.500
Total	$7.956

The rock excavation amounted to 880 cu. yds. and each laborer averaged .088 cu. yd. per hour. In the figures given above for earth excavation and rock excavation, by the item "waste" is meant the excavated material that it was necessary to take away; in other

words the surplus excavation. The length of the haul was about 2½ miles, and, where the contractor hired teams for the purpose, they were paid by the load at the rate of $1 per load. The figures given for "waste" are what the contractor actually hired teams to remove; but, in addition, he used some of his own teams, of which he kept no close record.

Brick masonry:	Per cu. yd.
Bricklayer, 1,180 hrs., at $1	$1.532
Helpers, 2,400 hrs., at $0.30	.935
Watchman, 480 hrs., at $0.17½	.109
Brick, 340 M, at $9	3.974
Cement, 460 bbls., at $1.80	1.075
Sand, 190 cu. yds., at $1	.247
Total	$7.872

A total of 770 cu. yds. of brick work were constructed; of this amount 73 cu. yds. were constructed of vitrified brick, costing $12.00 per M. Allowing for the extra cost of this vitrified brick brings the total cost of the brick masonry per cubic yard to $7.99. The vitrified brick masonry alone cost $8.12 per cu. yd. Each bricklayer averaged .652 cu. yd. per hour.

The plant used in the work and its cost were as follows:

Dynamo, 20 hp., and electricity for 4 months	$800
Compressor	250
Receiver	25
Air drills (Ingersoll-Rand, N. Y.), 3, at $110	330
Pumps, two 2-in. at $60, and one 1-in. at $30	150
Hand windlasses	100
Tools, boots, lights, gasoline, etc.	200

With the exception of the last two items, all of the plant was used in rock excavation alone. The earth section of the tunnel was worked from the outlet and there was little pumping required.

In the costs given above no charge has been made for plant, nor do the costs include office expenses of the contractor nor insurance of the men. For the information from which this article was prepared we are indebted to Mr. Curtis Hill, C. E., of St. Louis, Mo.

Cost of Pipe and Brick Sewers and Manholes in St. Louis.—This sewer, which was known as the Tam Avenue public sewer, was constructed in St. Louis, Mo., and consisted of 262.5 ft. of 24-in. pipe sewer and 154 ft. of 22-in. x 33-in. brick sewer and one manhole.

The brick portion of this sewer is under the Missouri Pacific Railroad tracks and the street railway tracks on the adjoining street. The tracks consist of five railroad and two street car tracks. The work here was done in open cut, the railway companies supporting their own tracks. The difficulty of working through and under these tracks somewhat increased the cost of the

brick sewer. Even with this, the cost of rock excavation is low, since the rock belonged to a class easily handled, being horizontally stratified limestone, more or less rotten on top, while the rest shattered well when blasted.

The drill holes were vertical (drilled with hand, or churn drills), spaced about 3 ft. along the center of the trench, driven about 2½ ft. deep and loaded with 1⅓ sticks, about 1 lb.) of 40% dynamite. The driller held his own drill, one man drilling, i. e., only one drill with one man to a hole. Limestone was ordinarily found in one to three foot strata, and the drill holes were driven to such a depth that the shot would tear out the strata. The layers of stone were of a depth at this place that holes about 1½ ft. deep loosened up the stone to the layer beneath. The top 4 or 5 ft. (and sometimes more) of the rock were rotten, and all that was necessary in the way of blasting was to loosen up the ledge, then sledge and pick it out. The shots were in the center of the trench, which would

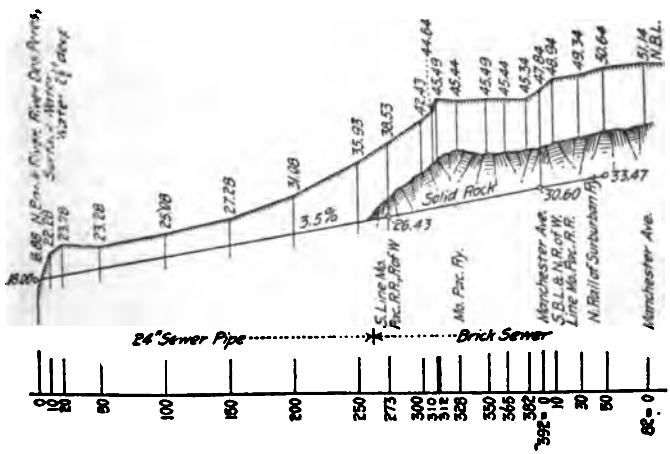


Fig. 6. Profile of Tam Avenue Sewer.

leave the sides of the trench ragged, but the same rotten rock can be sledged and dressed off to required width.

The trench was 3½ ft. wide. The width of rock excavation paid for is estimated to the extreme width of the brick work down to sub-grade. The railroad ballast is included in the earth excavation. All excavation costs include the labor of backfilling, disposal of surplus, bracing, etc., but no allowance is made for lumber for bracing, nor for the incidentals, such as care of tools, insurance, contractor's office expense, etc. No machinery was used.

24-In. Pipe Sewer.

Earth Excavation (5½ ft. cut; 150 cu. yds.).

	Total.	Per cu. yd.	Per lin. ft.
Foreman, 27 hrs., at $0.50	$13.50	$0.09	$0.05
Labor, 153 hrs., at $0.25	38.25	0.26	0.15
Total	$51.75	$0.35	$0.20

Pipe and Pipe Laying (262.5 lin. ft.).

	Total.	Per lin. ft.
Foreman, 10 hrs., at $0.50	$ 5.00	$0.02
Labor, 120 hrs., at $0.25	30.00	0.11
Bottomman, 63 hrs., at $0.30	18.90	0.07
Cement, 1-150 bbl., at $1.50	....	0.01
Pipe, per ft.	....	1.25
Total		$1.46
Excavation per lin. ft.		0.20
Grand total per lin. ft. pipe sewer		$1.66

22-In. x 33-In. Brick Sewer.

(154 lin. ft.)

Earth Excavation (9.2 ft. cut; 190 cu. yds.).

	Total.	Per cu. yd.	Per lin. ft.
Foreman, 53 hrs., at $0.50	$ 26.50	$0.14	$0.16
Labor, 630 hrs., at $0.25	162.50	0.85	1.05
Total	$189.00	$0.99	$1.21

Solid Rock Excavation (7 ft. cut; 135 cu. yds.).

	Total.	Per cu. yd.	Per lin. ft.
Foreman, 100 hrs., at $0.50	$ 50.00	$0.37	$0.32
*Drillers, 570 hrs., at $0.30	171.00	1.26	1.11
Labor, 460 hrs., at $0.25	115.00	0.85	0.75
Dynamite, 70 lbs., at $0.15	10.50	0.08	0.07
Total	$346.50	$2.56	$2.25

Brick Masonry (41 cu. yds.).

	Total.	Per cu. yd.	Per lin. ft.
Foreman, 54 hrs., at $0.50	$ 27.00	$0.66	$0.17
†Mason, 61 hrs., at $1.00	61.00	1.49	0.39
Helper, 61 hrs., at $0.25	15.25	0.37	0.10
Mortarman, 62 hrs., at $0.30	18.60	0.45	0.12
Brick, 18,200, at $8.50 per M	155.55	3.79	1.01
Cement, 25 bbls., at $1.50	37.50	0.91	0.24
Sand, 12 cu. yds., at $1.00	12.00	0.29	0.08
Total	$326.90	$7.96	$2.11
Earth excavation			1.21
Rock excavation			2.25
Total cost of brick sewer			$5.57

* At rate of ¼ cu. yd. per hour per driller.

† At rate of ⅔ cu. yd. per hour per mason.

Brick Manhole.
(4 cu. yds.)

	Total.	Per cu. yd.
Mason, 9 hrs., at $1.00	$ 9.00	$2.25
Helper, 9 hrs., at $0.25	2.25	0.56
Mortarman, 9 hrs. at $0.30	2.70	0.67
Brick, 1,800, at $8.50 per M	15.30	3.82
Cement, 2.5 bbls., at $1.50	3.75	.94
Sand, 1 cu. yd., at $1.00	1.00	.25
Total	$34.00	$9.48
Cast-iron (head), 490 lbs., at $0.02½	12.25	
Wrought-iron bands and steps, 102 lbs., at $0.04	4.08	
Total cost of manhole	$50.33	

The information given above was furnished by Mr. Curtis Hill, Chief Engineer of the Sewer Department of St. Louis, Mo., and published in *Engineering-Contracting*, March, 1906.

Cost of a Brick Sewer at Syracuse, Built by Tunneling.—The following data were published in *Engineering-Contracting*, Nov. 14, 1906.

The so-called tunnel line sewer of Syracuse, N. Y., was constructed for the purpose of draining some 600 acres of land. The area to be drained lies in a valley, surrounded entirely by a ridge of hills, so that the excavation for the sewer had to be done partly by the open cut method and partly by the tunnel method. The cost figures that follow are for a section of the sewer constructed by the latter method. The sewer has a total length of 4,717 ft. and, starting at Grumbach avenue (see Fig. 7), the first section of 470 ft. was constructed by the open cut method; then came 1,135 ft. of tunnel, 495 ft. of open cut, 670 ft. of tunnel, 1,240 ft. of open cut, 280 ft. of tunnel, and finally 431 ft. of open cut. The sewer is circular, 33 ins. inside diameter, constructed of two rings of brick laid in cement mortar, and was designed to flow one-half full. As originally planned it was proposed to have cuts under 30 ft. made by the open cut method; the contractor, however, decided to build the sewer for the distance of 495 ft. between the two longest tunnels in tunnel construction. All tunnel openings are permanent, manholes being built at these points, and also at places where the tunnel line intersects streets, a distance of about 600 ft. apart.

Open Cut Method.—Work on the first open cut section of the sewer was commenced at Grumbach avenue on Dec. 2, 1905. The cut ran from 13 ft. at Station O to 32 ft. to sub-grade at the first section of the tunnel (Station 4 + 70). The first 6 ft. of the cut was cast out by hand, but from this point to sub-grade a trenching machine was used to handle the material. The first material encountered was 7 ft. of loam clay and gravel, and underlying this was a stiff red clay containing stone and gravel, varying in size from pebbles to 12-in. boulders.

The trenching machine was built by the contractor. It consists of a bucket car mounted on wheels, and had a device at the top for use in hoisting the buckets. The latter were of iron, revolving type,

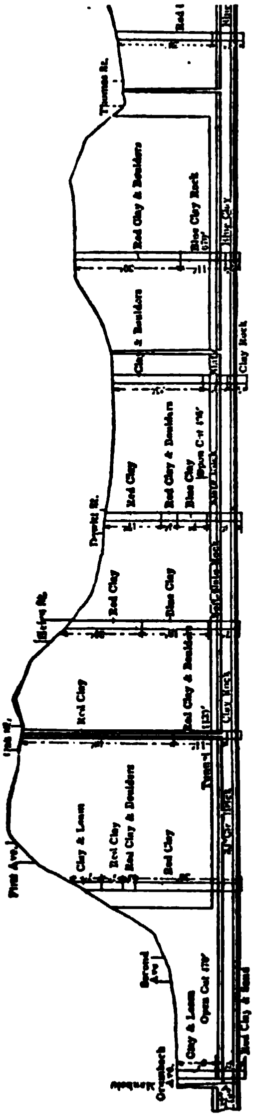


Fig. 7. Profile of Tunnel for Sewer.

¾ cu. yd. capacity, of the kind ordinarily used on trenching machines. The car ran on a track extending over the trench, spiked to cross ties laid on the ground, the rails being laid so that the car cleared the line of sheeting. A double drum stationary engine in an engine house, mounted on wheels, was used to operate the car and the hoisting apparatus. One drum of the engine was attached to the cable for moving the car; the other drum operates the cable for raising and lowering the buckets. The cable runs from the engine house to an A frame, and a working distance of 200 ft. can be made advantageously.

The operator, standing on the car in view of the trench and buckets, gave the signals to the engineer to raise or lower the buckets or to move the car forward or backward on the track. Buckets were distributed along the trench and when filled the operator dropped an empty one, picked up a filled bucket and carried it backward, dumping the material over the completed sewer. In this way the completed sewer was backfilled as rapidly as the work was finished. When it was necessary to move the machine ahead, rails were laid and the engine house moved forward under its own power, carrying the A frame along with it.

By Jan. 4, 404 ft. of the first 470 ft. of open cut sewer had been completed, the remaining distance being left open to allow the engineers distance for a backsight to project the line into the tunnel. This section was afterwards built to within a few feet of the tunnel opening, only enough room being allowed in which to raise and lower the buckets.

The sewer constructed in the open cut excavation was circular, 33 ins. in diameter, the invert being of second quality paving brick and the arch of ordinary sewer brick. The brickwork was laid on a cradle of 1-in. hemlock nailed to 2-in. square forms, the cradle being backed with concrete for 3 ins. underneath and 6 ins. at the spring line. The space below the spring line was also filled with concrete.

Tunnel Method.—Work on the tunnel section was first commenced at the western end (Station 4 + 70). It was planned originally, however, to start the shaft at Oak street and the shaft at De Witt street about the same time that the open cut excavation was commenced, and in this way start the tunnel excavation simultaneously in four headings. Later on the work was carried on in four headings.

The dimensions of the tunnel excavation were 7 ft. 9 ins. x 5 ft. 10 ins., and the materials encountered were a clay rock and in some instances slate rock. In the first section small pockets of clay and sand were encountered, which necessitated very close side sheeting. All of the drilling was done by hand, four holes, spaced about a foot from the side, being drilled in the face. The two upper holes were drilled about 18 ins. from the roof, the lower ones being from 18 ins. to 2 ft. from the floor. At first each hole was loaded with one stick of 40% dynamite, and all four holes blown at once. This threw down the whole face and was very effective. It was found, however, that the charge was too heavy for the tim-

bering to stand safely, and accordingly the two upper holes were loaded with 1½ sticks of dynamite and fired. After the muck had been cleared away the two lower holes were loaded with the same sized charge and fired. The result proved satisfactory. The holes were drilled from 2 ft. to 2½ ft., and the face thrown out by the blast had a depth of 18 ins. to 2 ft. Before a blast was fired a platform was laid at the foot of the face, and the material or muck was blasted out upon it. In this way the material was more easily handled.

The method of timbering the tunnel is shown in Fig. 8. All timber used in the tunnel was beech, which on account of its toughness did not splinter or brush. The timber consisted of 6-in. x 6-in. frames, spaced about 5 ft. centers. The cap and sill were 5½ ft. long and uprights were 6½ ft. long, with corners temporarily strapped with angle iron, which was withdrawn after overhead

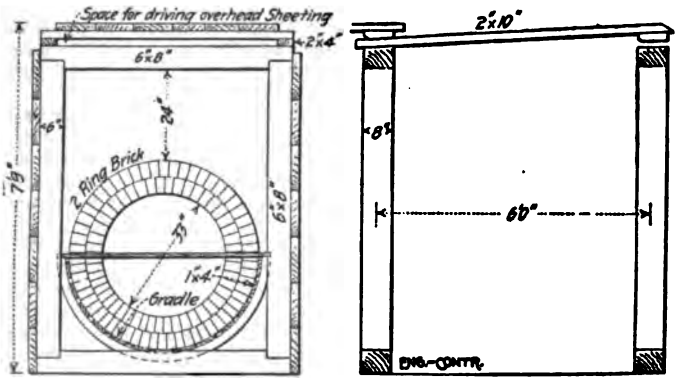


Fig. 8. Sewer in a Tunnel.

and sidebridging had advanced two frames. On top of the frames at each corner were blocks, on which was placed 2-in. plank, leaving a space for driving overhead sheeting. On account of this overhead sheeting causing a pressure on the plank placed on the blocks, the edge of the plank was beveled and the overhead sheeting pointed to allow it to enter the space.

The excavated matter was removed in buckets, similar to those described under open cut work. These buckets were placed on a platform car which ran on a 2-ft. gage track carried along as the tunnel progressed. The car was pushed to the mouth of the tunnel by one of the men, where it was raised by trenching machine previously described, and conveyed to the dumping ground. The excess of material was used in filling low land near the tunnel opening, the haul consequently being very short. The platform car was also used in carrying lumber and other materials into the tunnel, and in carrying out boulders, etc.

The foul air caused by the dynamite fumes, also from working so far in the tunnel without ventilation, was overcome by pumping fresh air into the tunnel through a 9-in. galvanized pipe by means of a rotary steam fan. In this manner the air was kept very pure, and within a short time after a blast was fired the fumes had passed away and the workmen were able to return to the breast of the heading to clear away the muck.

Some water was encountered, and this was pumped from the tunnel at the low points, as Station 4 + 70 and shaft at Oak street, by means of a steam siphon into the completed sewer. At the DeWitt street shaft the water was pumped out by a pulsometer, and in this way the tunnel was kept comparatively dry. In the section of the tunnel from Oak street to DeWitt street a very hard clay rock, bearing gypsum, was encountered, which proved not only hard to drill, but could not be blasted out satisfactorily. In addition water ran continually from the breast of the heading and also from the sides of the tunnel, making constant pumping necessary. The drillers were obliged to wear rubber suits. The rate of progress was about one-half as great as in the section from 4 + 70 to Oak street.

Cost Data on Tunnel Sewer Construction.—Cost data on the construction of a greater portion of the first section of the sewer built by the tunnel method are given below. These costs are for a total length of sewer of 1,047 ft., that is, for the sewer starting at Station 4 + 70 to within about 100 ft. of DeWitt street (see Fig. 7). In these data the cost of drilling per foot of hole could not well be separated from picking and shoveling into buckets, as some men worked on both. The drilling was all done by hand, and after a shot was fired the drillers shoveled the muck and trimmed up with picks. Water was, in general, taken care of with a steam siphon at one shaft and pulsometer at other. Hand bailing was occasionally resorted to.

From Jan. 15 to Feb. 22, in 35 days of actual work, 178 lin. ft. of tunnel was excavated, or an average of 4.94 ft. per day of ten hours. The allowed excavation was 45.18 cu. ft. per lineal foot of tunnel; consequently an average of 8.26 cu. yds. was excavated each day. The material was hard red clay, which worked well. The work was done by one gang working ten hours per day. The labor cost per day was as follows:

	Per day.	Total.	Per lin. ft.
6 men in tunnel	$2.00	$12.00	$2.43
1 sheeter	3.00	3.00	.60
1 foreman	2.50	2.50	.50
1 engineer	1.75	1.75	.35
4 men on top	1.75	7.00	1.42
1 waterboy	1.00	1.00	.20
Total		$27.25	$5.50

From Feb. 22 to March 23, three shifts of eight hours each per day were worked by the men in the tunnel. The actual number of days worked was 30, and in this time 115 lin. ft. of tunnel was excavated, an average of 3.83 lin. ft. per 24 hours, or 1.28 lin. ft.

per 8-hr. shift. The material was clay rock with from 12 ins. to 20 ins. of gypsum in the bottom. This material was very hard and progress was consequently slow. The labor cost per day was as follows:

	Per shift.	Per day.	Per lin. ft.
6 men in tunnel	$2.00	$36.00	$9.40
1 sheeter	3.00	6.00	1.57
2 men on top	1.75	7.00	1.82
1 engineer	1.75	3.50	0.91
1 waterboy	1.00	2.00	0.52
Total		$54.50	$14.22

The 6 men in the tunnel worked an 8-hr. shift; all others worked 12 hours.

From March 23 to April 4, two headings were worked, the men in the tunnel working in three shifts of eight hours each. The actual number of days worked was 13, and in this time the tunnel was advanced 216 ft., or 8.31 ft. per heading per 24 hours. At the shaft heading at Oak street the material was a soft clay rock which worked easily. In the west heading the gypsum continued until March 14, when it disappeared entirely.

The labor cost per day was as follows:

	Per shift.	Total per day.	Per lin. ft.
12 men in tunnel	$2.00	$72.00	$4.33
2 sheeters	2.00	12.00	0.72
6 men on top	1.75	21.00	1.26
2 engineers	1.75	7.00	0.48
1 team	4.00	8.00	0.48
1 tag line boy	1.25	2.50	0.15
Total		$122.50	$7.36

The materials used in the work from Jan. 15 to April 4, when the first section of the tunnel was completed, were as follows:

	Rate.	Total.	Per lin. ft.
2,255 lbs. dynamite	$0.14	$315.70	$0.63
32 tons coal	3.50	112.00	.22
110 gals. olive oil	.45	49.50	.10
50 gals. engine oil	.34½	17.25	.03
860 electrical exploders	.03½	30.10	.06
55,000 ft. B. M. lumber	16.00	880.00	1.74
Total		$1,404.55	$2.78

The total cost of the tunnel work from Jan. 15 to April 4, a total progress of 504 ft. having been made, was as follows:

	Per day.	Total.
Labor, 35 days	$ 27.25	$ 953.75
Labor, 30 days	54.50	1,635.00
Labor, 13 days	122.50	1,592.50
Total		$4,081.25
Blacksmith, 156 hrs., at 25 cts.		39.00
Materials		1,405.55
Repairs		100.00
Grand total, 504 ft., at $11.16		$5,624.80

Part of blacksmith work, sharpening picks, etc., was done by one

of the men on top and is not separated from cost of labor of men on top. Men on top also made wedges and assisted the sheeter in cutting frames, etc. One man on top acted as conductor on the bucket car.

The above costs include not only the excavation, but also the sheeting of the tunnel, and in addition a small amount of concrete work. The cost of sheeting the tunnel was approximately as follows:

	Total.	Per lin. ft.
Labor	$ 546	$1.08
Timber	880	1.74
Total	$1,426	$2.82

The labor cost on concrete amounted to about $110; deducting this and the cost of sheeting from the total cost ($5,624.80), we have $4,088.80 as the cost of excavating the tunnel. The average cost per lineal foot of excavation would then be $8.11. At the allowed excavation, 45.18 cu. ft. per lineal foot, the average cost of excavation per cubic yard for the 504 ft. was $4.87. The labor referred to in the foregoing tables as "men on top" included man tending dump, conductor on bucket car, cutting wedges and all incidental work.

Brickwork in First Section of Tunnel.—The sewer construction in the tunnel is the same as in the open cut, or 33-in. circular, 2-ring brick, laid on a cradle. The allowed thickness was 9 ins., or 8.25 cu. ft. per foot of sewer. All space below the spring line is filled with second-class natural cement, mixed in a 1 : 3 : 7 proportion. From the spring line of the sewer to the roof tunnel the space is backfilled with carefully rammed earth. The brickwork was carried 4 ft. from the opening of the tunnel, making 500 ft. of completed sewer for the first section.

The brickwork, backfilling, etc., for the 500 ft. of sewer were completed in 18 days of 12 hours each, the cost being as follows:

	Rate.	Total.	Per lin. ft.
1 mason	$4.50	$ 4.50	$0.16
1 mason	3.00	3.00	.11
5 men	2.00	10.00	.36
Total		$17.50	$0.64

The materials used were as follows:

	Rate.	Total.	Per lin. ft.
75,000 brick	$7.50	$ 562.50	$1.12
115 bbls. cement	1.20	138.00	.27
105 cu. yds. gravel	1.25	131.25	.26
Total		$ 831.75	$1.66
18 days labor, at $17.50		315.00	.64
Grand total		$1,146.75	$2.30

The above work included 153 cu. yds. of brickwork, 110 cu. yds. of concrete and 310 cu. yds. of backfilling. The latter was done by the men who assisted the bricklayers, each 5-ft. section taking four men about 1½ hours. The labor cost of the backfilling was $113.40. The labor on concrete consisted of about 550 hours' work

at 20 cts. per hour, or $110. Deducting these amounts from the total of $1,146.75, we get $923.35 as the cost of the brickwork for the first section of sewer.

On this basis the cost per lineal foot was $1.85, and the cost per cubic yard of brickwork was $6.03.

The cost of the forms or cradles used in construction of brickwork could not be separated from lumber cost. The cost was very slight.

Shaft at Oak Street—The dimensions of the shaft at Oak street were 10 ft. x 16 ft. on top; the bottom measured 9 ft. x 15 ft. The shaft was sunk to a depth of 58 ft. The materials encountered followed very closely those shown by the test borings as shown in Fig. 7. The shaft was divided into three compartments, the middle compartment, used for hoisting buckets, being 6 ft. in clear and the end compartments being 3½ ft. in clear. One end compartment was used for a ladderway, the other end compartment being used for a pumpway. Beech timber was used and sets or frames were all 6-in. x 8-in. timber; the sidewalls were 16 ft. long, braces 6½ ft. long. The lagging was 2-in. beech. All of the drilling on shafts and tunnel was done by hand.

A machine was used at this shaft for hoisting and disposing of excavated matter from the tunnel. It consisted of a platform car, 13 ft. long by 8 ft. wide, mounted on standard gage steel trucks. Buckets were hoisted through a hole 4 ft. 10 ins. by 6 ft. in the platform. Over this hole was an iron angle frame, at the top of which was the hoisting device for raising and lowering the buckets. The mechanism is similar to that of the trenching machine, previously described. A 4-cylinder, 4-cycle gasoline engine of 30 hp. furnished the power to operate the hoisting apparatus and to move the car. The engine acts through a two-way friction clutch; one way throws in a single drum and operates the cable which hoists or lowers the buckets; the other way throws gears connected to a sprocket on the car wheel, causing the car to move forward or backward, the direction being controlled by a marine reversing device. The bucket operator stands between the bucket opening and one end of the car. The engine and drum are at the other end of the car and the engineer is stationed near the opening, where he can operate levers and at the same time have a clear view of the shaft below. The machine was designed and built by the contractor for the work.

In sinking the shaft, red clay was encountered to within 15 ft. of the bottom, when some boulders were reached, and in the bottom was 3 ft. of clay rock. The shaft was sunk in 14 days of 10 hours each, the cost being as follows:

Labor.

	Rate.	Total.	Per lin ft.
7 men in shaft	$2.00	$14.00	$3.38
4 men on top	1.75	7.00	1.69
2 teams	4.00	8.00	1.93
1 engineer	1.75	1.75	.42
1 tag line boy	1.25	1.25	.30
Total		$32.00	$7.72

Material.

	Rate.	Total.	Per lin. ft.
250 lbs. dynamite	$0.14	$35.00	$0.60
100 electrical exploders	3.50	3.50	.06
4 tons coal	3.50	14.00	.24
Total		$52.50	$0.90

Summary.

	Rate.	Total.	Per lin. ft.
Material	...	$52.50	$0.90
30 hrs., blacksmith	$0.25	7.50	.13
14 days, labor	32.00	448.00	7.72
19,300 ft. B. M. lumber	16.00	308.80	5.32
Total, 58 ft., at $14.07		$816.80	$14.07

The manhole in the Oak street shaft was 5 ft. inside diameter with a 1-ft. wall of brickwork to within 20 ft. of the surface, where it was reduced to a 9-in. wall, and 5 ft. from the surface was drawn in from 5 ft. diameter to 2 ft. to allow for an iron cover. Around the sewer the size of the manhole and as far up as the springline was solid brickwork to insure a solid foundation for the manhole.

First-class Portland cement concrete was used as backfilling around the manhole for the full dimensions of the shaft from the springline of the sewer to the top of the normal tunnel excavation; from this point to the surface the backfilling in the shaft was earth. The timbering in both shaft and tunnel was allowed to remain in place permanently.

The cost, including labor on brickwork, backfilling, tending masons and all incidental work, was as follows:

Labor.

	Rate.	Total.
1 mason	$4.50	$ 4.50
1 mason	3.00	3.00
5 men	1.75	8.75
Per day of ten hours		$16.25
	Rate.	Total.
5 men	$1.75	$8.75
	Rate.	Total.
4 2/5 days	$16.25	$71.50
1½ days	8.75	13.13
Total labor		$84.63

Material.

	Rate.	Total.
19,500 brick	$ 7.50	$146.25
70 iron steps	.08	5.60
1 iron cover	10.00	10.00
24 bbls. cement	1.70	40.80
19 cu. yds. gravel	1.25	23.75
Total material		$226.40

Summary.

Labor	$ 84.63
Material	226.40
Total	$311.03

The measured work complete was 37 cu. yds. brickwork, 10 cu. yds. concrete, 65 cu. yds. backfilling.

Shaft at De Witt Street.—The dimensions of the shaft at De Witt street were 9 ft. by 15 ft. The shaft was sunk to a depth of 36½ ft., through red clay mixed with a few boulders, and 4 ft. of clay rock at the bottom. The shaft was sunk in seven days of ten hours each, the cost being as follows:

Labor.

	Rate.	Total.	Per lin. ft.
6 men in shaft	$2.00	$12.00	$2.31
2 men on top	1.75	3.50	.67
1 foreman	2.00	2.00	.38
		$17.50	$3.36
7 days	$17.50	$122.50	$3.36
Engineer, 5 days	1.75	8.75	.24
Sheeter, 5 days	3.00	15.00	.41
21 hours, blacksmith	.25	5.25	.14
Total		$151.50	$4.15

Material.

	Rate.	Total.	Per lin. ft.
110 lbs. dynamite	$0.12	$13.20	$0.36
50 electric exploders	3.50	1.75	.04
2 tons coal	3.50	7.00	.20
10,500 ft. B. M. lumber	16.00	168.00	4.60
		$189.95	$5.20

Summary.

	Total.	Per lin. ft.
Labor	$151.50	$4.15
Material	189.95	5.20
Total, 36½ ft., at $9.35	$341.45	$9.35

Cost Data on Second Section of Tunnel.—The second section of the tunnel, from Oak street to De Witt street, 543 ft., was driven in 139 days' labor of 24 hours each. The average progress was about 3.9 ft. per day, or 1.3 ft. per shift of eight hours.

The material from entrance (Station 9 + 88) to Station 10 + 12 was clay rock, which broke up easily, but from this point to Station 15 the material was a hard clay rock bearing gypsum, much of which was of a flinty nature and very difficult to handle. Another disagreeable feature of this section was the large amount of water encountered, which was continuous from Station 10 + 50 to Station 15. Men were obliged to wear rubber suits and pumping and bailing were constantly necessary.

The cost of the work was as follows:

Labor.

	Per shift.	Per day.	Per lin. ft.
4 men in tunnel	$2.00	$24.00	$6.15
1 sheeter	3.00	6.00	1.54
3 men on top	1.75	10.50	2.69
1 engineer	1.75	3.50	.90
Total		$44.00	$11.28

Labor (Continued).

139 days	$44.00	$6.116.00	$11.28
77 days extra men bailing	2.00	154.00	.28
62 days blacksmith	1.75	108.50	.20
62 days waterboy	1.00	62.00	.11
Grand total for labor		$6,440.50	$11.87

Materials.

	Rate.	Total.	Per lin. ft.
400 lbs. dynamite	$ 0.14	$ 56.00	$0.10
945 lbs. dynamite	12.00	113.40	.21
843 exploders	3.50	29.50	.05
280 gals. olive oil	45	126.00	.23
51 gals. engine oil (bbl.)	.34½	17.60	.03
35 tons coal	3.50	122.50	.22
		$466.00	$0.84
37,400 ft. B. M. lumber	$16.00	$598.40	$1.10

Summary.

	Total.	Per lin. ft.
Labor	$6,440.50	$11.87
Material	466.00	.84
Lumber	598.40	1.10
Total, 543 ft. of tunnel at $13.82	$7,504.90	$13.81

As in the case of the first section the above figures include the cost of sheeting and a small amount of concrete.

The cost of the material for the sheeting was $598.40, and the labor cost was approximately as follows:

695 hours, at 25 cts.	$173.75
1,300 hours, at 17½ cts.	243.25
Total	$417.00

	Total.	Per lin. ft.
Lumber	$ 598.40	$1.10
Labor	417.00	.77
Total	$1,015.40	$1.87

The cost of the labor on concrete was approximately $149.50; deducting this sum and the cost of sheeting from the total of $7,504.90, and we get $6,340 as the cost of excavating the second section of the sewer. As the second section of the tunnel was 543 ft. long, the actual average cost per lineal foot was $11.67; the average cost per cubic yard of excavation was $7.00.

Cost of Third Section of Tunnel.

Section 3 of the tunnel, from Station 15 + 45.50 to 21 + 50, or 605 ft., was driven in 95 days of 24 hours each, or 6.36 ft. per 24 hours. Work on Section 3 began on Aug. 22, with gang working east. On Oct. 8, another shaft was opened and gang started west from shaft No. 3. The two headings met on Nov. 2. The laborers in tunnel, and sheeters, worked in 8-hr. shifts, and engineers and men on top were on duty 12 hours. The material was clay rock, not hard, and therefore easily handled. In this section the engi-

neer attended to blacksmithing, so there was no charge against this item.

Labor Cost.

	Rate.	Total.	Per lin. ft.
855 days, labor in tunnel	$2.00	$1,710.00	$2.84
285 days, sheeters in tunnel	3.00	855.00	1.41
190 days, engineers	2.00	380.00	.63
285 days, labor on top	1.75	495.75	.82
Total		$3,440.75	$5.70

From allowed excavation, the cost is $3.41 per cu. yd.

Material.

	Total	Per lin. ft.
21 tons coal, at $3.25 ton	$ 68.25	$0.11
1,665 lbs. dynamite, at $11.50 cwt	191.48	.31
762 caps, at $3.50	26.67	.04
190 gals. olive oil, at $0.38	72.20	.11½
20 gals. engine oil, at $0.48	9.60	.01½
3 mos. telephone, at $2.00	6.00	.01
38,682 ft. B. M. lumber, at $14.00 M	441.54	.73
Total	$815.74	$1.33

From allowed excavation, cost is $0.80 per cu. yd.

	Total	Per lin. ft.
Labor	$3,440.75	$5.70
Material	815.74	1.33
Total	$4,256.49	$7.03

Setting Cradle and Placing Concrete.

Labor.

	Rate.	Total.	Per lin. ft.
96 days, labor in tunnel	$2.00	$192.00	$0.31
24 days, engineer	2.00	48.00	.08
48 days, labor on top	1.75	84.00	.14
		$324.00	$0.53

Material.

	Rate.	Total.	Per lin. ft.
240 cu. yds. gravel	$1.10	$264.00	$0.43
204 bbls. cement	.98	200.90	.33
2,828 ft. B. M. lumber for cradles	20.00	56.56	.09
		$521.46	$0.85
Grand total		$845.66	$1.37

Brickwork and Backfilling Over Sewer.

Labor.

	Rate.	Total.	Per lin. ft.
22 days, mason in tunnel	$3.50	$ 77.00	$0.13
22 days, mason in tunnel	3.00	66.00	.11
132 days, labor in tunnel	2.00	264.00	.43
24 days, engineer on top	2.00	48.00	.08
72 days, labor on top	1.75	126.00	.21
		$581.00	$0.95

Material.

	Rate.	Total.	Per lin. ft.
92,000 brick	$7.50	$690.00	$1.12
110 yds. sand	1.10	121.00	.20
180 bbls. cement	.98	176.40	.29
Total		$987.40	$1.61
Grand total		$1,568.40	$2.56

The labor on top under "setting cradles and placing concrete" was for lowering cradles, mixing concrete and lowering same.

The labor on top under "brickwork" was for lowering brick and mixing and lowering mortar.

The work is being done by contract under the direction of Henry B. Brewster, Assistant City Engineer, to whom we are indebted for the above information.

Cost of a Sewer Tunnel at Chicago, Using a Hydraulic Shield.—The following data were published in *Engineering-Contracting,* Feb. 6, 1907.

The Lawrence avenue conduit of the new intercepting sewer system of Chicago, Ill., is tunnel work through clay. The completed conduit will be 16 ft. inside diameter, lined with 162 ins. of brickwork in four rings, backed by a ring of solid timbering 8 ins. thick. The bore being made by the shields is, thus, 20 ft in diameter. From Lake Michigan to the Chicago River the conduit is 8,220 ft. long and there is, in addition, an intake tunnel for flushing water extending out under the lake. This article refers only to the land portion of the conduit, which is being built by M. H. McGovern, Contractor, at a contract price of $79.50 per lineal foot.

The conduit is being constructed by driving two shields in opposite directions from a central shaft, about the top of which are located the contractor's power house, shops, sawmill, storage yards and the spoil bank. The shield work is unusual in the fact that a close lining of timber segments is used to keep the clay in place and to take the thrust of the jacks used to advance the shields. This timbering is described fully in a succeeding paragraph, but it is important to note here that it serves its purpose admirably, being neither crushed nor distorted by the pressure of the jacks.

Shield Construction and Operation.—Fig. 9 is a diagram longitudinal section of the shield and tunnel lining and Fig. 10 is an enlarged detail of the cutting edge of the shield. The structural features and the principal dimensions of the shields are given clearly by these illustrations. Each shield is operated by 24 hydraulic jacks of 60 tons capacity and good for 6,000 lbs. pressure. These jacks are of the Watson-Stillman type with 8-in. barrels and 5.75-in. plungers. They are operated with 3,500 lbs. per sq. in. working pressure and 2,000 lbs. per sq. in. release pressure. Each shield weighs about 8 tons and cost $8,000.

Excavation.—The tunnel is through clay which holds a nearly vertical working face and becomes quite hard in places. This clay is excavated principally by means of draw knives of the form illustrated by the sketches in Fig. 11 and the photographic view, Fig. 12. The knives are operated like a draw shave for working wood. When the clay is soft, two men operate the knife, one grasping each handle, but, when the clay is hard, a third man is employed, who also takes hold and bears down. A strip of clay nearly 5 ft. long is shaved off with each stroke of the knife and is passed to a

third man, who rolls it up and casts it over his shoulder to the muckers behind.

The draw knives, made by the contractor's blacksmith, are of 7/32 x 1¼-in. spring steel self-annealed in air. Two forms of knife are used, one for soft and one for hard clay; the difference in form is in the angle which the cutting edge makes with the handle, this angle being 45° for soft clay and 20° for hard clay. The blades wear down to a width of about ¾-in. and then break at the center. Other details and dimensions are given by the sketches, Fig. 11.

Work is carried on continuously in 8-hr. shifts, the usual arrangement being to operate three shifts of miners in one drift and

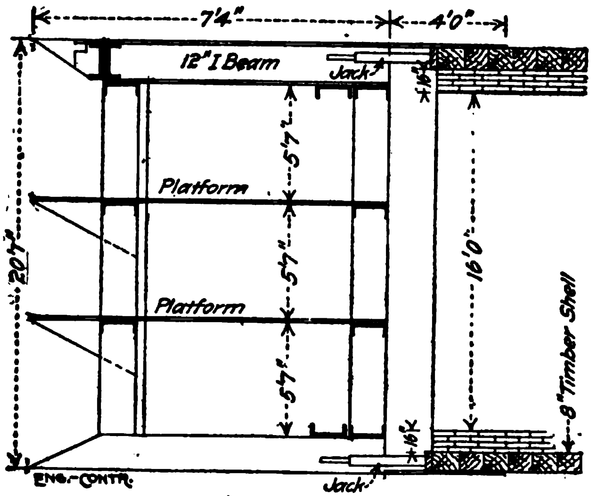


Fig. 9.—Tunnel Shield.

two shifts of miners and one shift of masons in the other drift, the masons' shift working the two drifts alternately. Each shift of miners is made up as follows:

	Per shift.	Per 24 hrs.
1 foreman, at $5	$ 5.00	$ 15.00
14 miners, at $3.75	52.50	157.50
12 muckers, at $3.25	39.00	117.00
2 valvemen, at $3.50	7.00	21.00
4 timbermen, at $3.50	14.00	42.00
2 switchmen, at $2	4.00	12.00
3 drivers, at $2.25	6.75	20.25
Totals	$128.25	$384.75

This crew is divided between the two drifts and has averaged

7 lin. ft. of excavation per shift in each drift, or 14 ft. per shift in both drifts. The bore being 20 ft. in diameter, there are 11.63 cu. yds. of excavation per lineal foot of tunnel. Therefore, $14 \times 11.63 = 163$ cu. yds. of material are taken out every 8 hours at a labor cost for mining, mucking, timbering and haulage in tunnel of $128.25, or 79 cts. per cu. yd.

Timbering.—The timbering consists of a solid lining 8 ins. thick composed of rings of 4-ft. segments laid close. This timbering is placed by the mining gangs inside the tail of the shield, and as fast as the shield advances. The segments are prepared in the contractor's sawmill by a separate gang working one 8-hr. shift per day. Since about 495 ft. B. M. of lumber is required for timbering each lineal foot of tunnel, the millwork is an important detail.

The timber used for the lining is rough hemlock, costing $18 per M. ft. B. M. It is delivered to the work in 6 x 8-in. pieces about 12 ft. long and is then sawed into segments 4 ft. long, 6 ins. wide and 8 ins. deep; each segment has its ends cut to true radial planes and its back to a true circular arc. The machines for this work are installed in a building at the contractor's plant, and consist of

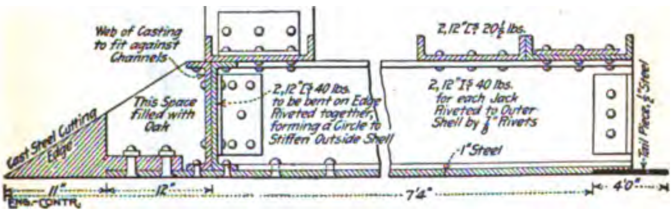


Fig. 10.—Cutting Edge of Shield.

a circular saw, a band saw, a band saw sharpener and minor tools. The circular saw is fitted with a table which swings with just the proper angle with respect to the saw to give the ends of the segments the correct bevel. The band saw cuts the back of the segment to the true circular arc and is fitted with a table which swings on the proper curve to effect this. In operation the 6 x 8-in. pieces are brought to the rear of the building and slid endwise through a window directly onto the table of the cutting-off saw.

The sawyer first takes off a crop end to get the proper bevel; he then turns the stick half-way over, shoves it along the table until the end comes against the stop and cuts it off. The stick is then turned again, pushed ahead against the stop and cut off. These operations are repeated for the third segment. As the segments are sawed off they are piled up by the side of the band saw. The band sawyer takes the pieces one at a time, adjusts them on the swinging table and cuts their backs to the desired arcs, and they are ready to go to the work. Each sawyer has one helper, and there are two other laborers to bring the sticks to the mill

and pass them to the cutting-off saw. The sawmill force works one 8-hr. shift per day, and is organized as follows:

	Per shift.
1 fireman, at $5	$ 5.00
1 engineer, at $5	5.00
2 sawyers, at $3.50	7.00
4 laborers, at $3.00	12.00
Total	$29.00

This sawmill gang turns out all the segments necessary to keep the work going in both drifts. The average advance of each drift is 21 ft. per day, and there being 495 ft. B. M. of timber per lineal foot of lining, this gang turns out $495 \times 42 = 20,790$ ft. B. M. of finished segments at a labor cost for sawing of $29, or about $1.40 per thousand feet.

Lining.—The 16-in. brick lining inside the timbering is placed

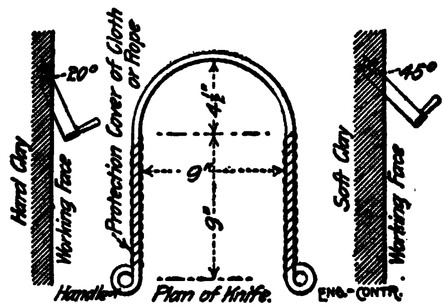


Fig. 11.—Draw Knife.

by a separate mason gang. It amounts to 3.42 cu. yds. of brickwork per lineal foot. The mason gang is organized as follows:

	Per shift.
7 masons, at $9	$ 63.00
17 helpers, at $2.75	46.75
10 laborers, at $2.50	25.00
2 drivers, at $2.25	4.50
Total	$139.25

The mason gang lays 20 lin. ft. or 68.4 cu. yds. of lining per shift at a cost for labor and haulage in tunnel of $2.04 per cu. yd., or $6.96 per lineal foot.

Haulage.—The muck is hauled from the working faces to the shaft in tunnel and from the shaft top to the spoil bank on surface in cars drawn by mules. The same cars are taken back loaded with brick, lining segments or other materials, so that they run loaded both ways. In the tunnel the hauling is done by the mining and the mason gangs, but a separate lift gang handles the cars on the elevator, and still another gang hauls them from the shaft top

to the spoil bank. This spoil bank is located about a hundred yards from the shaft top, since the clay is being saved for sale, it being of a kind particularly suited for certain burnt clay products.

The lift gang works three 8-hr. shifts per day, and is organized as follows:

	Per shift.	Per 24 hrs.
2 cagemen, at $3	$ 6.00	$18.00
4 laborers, at $2.50	10.00	30.00
Total	$16.00	$48.00

The dump gang works three 8-hr. shift and is organized as follows:

	Per shift.	Per 24 hrs.
1 hoisting engineer, at $5	$ 5.00	$ 15.00
1 fireman, at $4	4.00	12.00
16 laborers, at $2.75	44.00	132.00
2 drivers, at $2.25	4.50	13.50
Totals	$57.50	$172.50

From these figures we can make an approximation of the cost of hoisting and dumping. Considering the cost of hoisting first, it is

Fig. 12.—Draw Knife.

to be noted that this is divided between the work of hoisting the muck and of lowering the brick, timber and mortar materials. We will, therefore, estimate the total cost of hoisting per day, and prorate this sum between the two. Assuming that one-half the fireman's wages and one-fourth the coal consumption are chargeable to hoisting, we have the following figures:

	Per day.
2 cagemen, at $3 per shift	$18.00
4 laborers, at $2.50 per shift	30.00
1 hoisting engineer, at $5 per shift	15.00
½ fireman, at $3.50 per shift	5.25
5 tons coal, at $3 per ton	15.00
Total	$83.25

Taking the quantities given elsewhere in the article we can

figure the weight of muck hoisted and the weight of materials lowered per lineal foot of tunnel as follows:

11.63 cu. yds. muck, at 3,000 lbs. per cu. yd...17.45 tons.

As 42 lin. ft. of tunnel are excavated each 24 hours, the weight of muck hoisted during that time is 733 tons. Turning now to the materials lowered, we have:

	Tons.
0.91 cu. yds sand, at 2,700 lbs. per cu. yd.	1.23
41.2 cu. ft. timber, at 35 lbs. per cu. ft.	0.72
1,650 bricks, at 4½ lbs. per brick	3.71
Total weight of materials	5.66

This total multiplied by 42 ft. gives 238 tons of materials lowered every 24 hours. The total tonnage of material handled is, therefore, 971 tons at a cost of 8.57 cts. per ton, of which about one-third, or 2.8. cts., are chargeable to lowering materials and two-thirds, or 5.68 cts., are chargeable to hoisting muck. The total yardage of muck hoisted every 24 hours is 11.63 × 42 = 489 cu. yds. The estimated cost of operating the hoist for 24 hours being $83.35, we have ($83.25 ÷ 489) ⅔ = 11⅓ cts. per cu. yd. as the cost on the above assumptions of hoisting the muck.

The cost of dumping per 24 hours as given above is $172.50, and a part of this is chargeable to loading materials and hauling them to the shaft head. It is probably fair to assume that at least two-thirds of the total cost is chargeable to hauling and dumping muck. As 489 cu. yds. of muck are hauled and dumped each 24 hours, we have ($172.50 ÷ 489) ⅔ = 23.4 cts. as the cost per cu. yd. on the above assumptions.

Plant.—The contractor's plant is housed in wooden buildings grouped around the head of the shaft and comprises the following machinery: Power plant: two 100 h.p. boilers, one dynamo and dynamo engine, 20 h.p.; one lift; one emery wheel; one 100 h.p. air compressor; one positive blower and 10 h.p. blower engine; two 50 h.p. hydraulic pressure pumps, and one 40 h.p. cage hoisting engine. Sawmill: one 80 h.p. boiler, one 50 h.p. engine, and the saws, etc., previously itemized. On the dump: one 15 h.p. hoisting engine boiler. The estimated first cost of this plant is $30,000. About 20 tons of coal per day (24 hrs.) at a cost of $3 per ton are required to operate it. The plant gang works three 8-hour shifts and each shift is made up of:

	Per shift.	Per 24 hrs.
1 hydraulic pump engineer, at $5	$ 5.00	$ 15.00
1 hoisting engineer, at $5	5.00	15.00
1 fireman, at $3.50	3.50	10.50
1 machinist, at $4	4.00	12.00
1 machinist's helper, at $2.75	2.75	8.25
1 electrician, at $4	4.00	12.00
1 blacksmith, at $4	4.00	12.00
1 blacksmith's helper, at $2.50	2.50	7.50
1 carpenter, at $5	5.00	15.00
1 trackman, at $3.50	3.50	10.50
1 barnman, at $3.50	3.50	10.50
2 laborers, at $2.50	5.00	15.00
Totals	$47.75	$143.25

Office Force.—The office force consists of seven men and its work is divided into two 12-hour shifts. It is made up of:

	Per month.
1 general manager, at $400	$133.00
2 superintendents, at $150	300.00
2 timekeepers, at $75	150.00
1 receiving clerk, at $75	75.00
1 bookkeeper, at $75	75.00
Total	$733.00

The general manager has charge of several jobs and about one-third of his time is chargeable to the work being described. Dividing the total wages by 30, we get $24.33 as the labor cost of the office force per day.

Summary of Costs.—The daily cost of labor, summarized from the above figures, is as follows:

Office force	$ 24.33
Dump gang	172.50
Lift gang	48.00
Mason gang	139.25
Sawmill gang	29.00
Drift gang	384.75
Plant gang	143.25
Lock tender	9.00
Total	$950.08

The cost of lumber as given above is $18 per M ft. B. M., and the cost of coal is $3 per ton. Estimating the cost of brick at $9 per thousand, of cement at $1.50 per barrel and sand at $1 per cu. yd., we get the following as the cost per lineal foot of the conduit exclusive of interest and depreciation on plant:

	Per lin. ft.
495 ft. B. M. of timber, at $18	$ 8.91
0.48 ton coal, at $3	1.44
1,650 bricks, at $9 per M	14.85
3.38 barrels cement, at $1.50	5.07
0.91 cu. yd. sand, at $1	0.91
Labor, $950.08 per day	22.62
Total	$53.60

This does not include the cost of sinking the shaft, nor does it include plant interest, depreciation and repairs.

Cost of a 13½-ft. Sewer Tunnel at Cleveland, Using a Hydraulic Shield.*—The method of building large sewers by tunneling is becoming increasingly popular, not only because it is usually cheaper than open cut work in soft ground, but because there is no obstruction of streets and no settlement of buildings adjacent to the sewer. Unfortunately, however, the use of a hydraulic shield is little understood by most contractors, and less is known about the actual cost of such work. We believe the following data are the first itemized costs of shield work that have appeared in the technical press; and, while a few of the items are probably not absolutely correct, the data are reliable in the main, and serve to give

**Engineering-Contracting,* July 25, 1906.

a very close estimate of the cost of similar work. Before giving the figures of cost, a word as to the conditions:

Most of the main intercepting sewer of Cleveland, Ohio, was built in open cut, the top width of trench being 20 ft. and the depth averaging 40 ft. Two sets of Wakefield sheet piling were required, the upper set being 28 ft. long. The sheet piling was well driven, but in passing certain brick buildings, enough quicksand leaked under the sheeting to cause a settlement of the buildings, and resulting cracking of the walls. The trench was through dry sand, wet sand, quicksand, and clay and sand mixed. As a result of the damage to one building it was decided to build the remainder of the sewer by the tunnel method. The contract price for the 13½-ft. sewer in open cut (40 ft. deep) had been $71 per lin. ft. The contractor agreed reluctantly to undertake the building of the sewer by the tunnel method for $60 per lin. ft., and, as we shall see, made a good profit at this price. The tunnel work proceeded day and night at a rate of 250 ft. a month, as compared with 135 ft. per month when the open cut method was used. One advantage of the tunnel work is that it can be carried on continuously, day and night, and there is no interruption on account of bad weather. Moreover, it requires fewer laborers than the open cut method, under the conditions above stated.

The secret of the modern success in driving tunnels through quicksand and other soft materials lies in the use of the hydraulic shield. A shield is a section of steel tube, open at both ends. The forward end is provided with cutting edges, and, in very soft materials, it is provided with trap doors through which the material is excavated. The shield is shoved forward about 2 ft. at a time, by means of hydraulic jacks; and the tunnel lining is built up inside the rear part of the shield, ready for the next shove. In this particular case a brick lining was used, and the hydraulic jacks bore against blocks of wood laid on this lining when shoving the shield ahead. Where the ground is so porous that the water flows in faster than it can be pumped out, the tunnel is kept full of compressed air. The pressure of the air depends entirely upon the pressure of the outside water at the face of the shield. In this particular work an air pressure of 5 lbs. per sq. in. was ordinarily sufficient, although in a few soft spots a pressure of 9 lbs. was used. With such low pressures as these there is no danger that the men will get the "bends." And there is no danger of "blowouts" at the face of the shield where the air pressure is light, and the covering of earth over the shield has a fair thickness. In a word, this sort of sewer tunneling by the shield method is not at all hazardous; and, it is surprising, indeed, to note how few contractors have had the courage to try it. Perhaps the stories of the difficulties encountered in driving tunnels under rivers (which is a wholly different matter) have served to frighten contractors and engineers generally.

Regarding keeping the shield to line and grade, no difficulty need be experienced in sewer work of this character. By making a

mark in the earth at the face of the shield, it is easy to see whether the shield is moving in a straight line or not. If the shield is moving off to one side, simply relax the pressure on the hydraulic jacks of the opposite side, and the shield is easily brought to line. In similar manner it is kept to grade. The jacks are so connected by piping that any one of them can be cut out. All that is needed is careful watching, and the shield can be easily kept to line. A cut showing the general dimensions of the shield is given herewith (Fig. 13).

We now come to the details of the work.

The sewer is 13½ ft. in diameter and was built of four rings

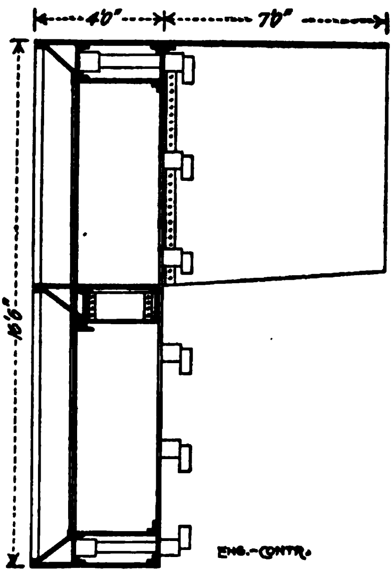


Fig. 13.—Tunnel Shield.

of No. 1 shale brick laid in Portland cement mortar. The masonry, from a point 2 ft. below the spring line to a point 4 ft. from the crown of arch, was laid in Flemish bond, keyed in with row-lock masonry.

The air lock consisted of a section of the sewer included between two brick bulkheads, 2 ft. thick and 24 ft. apart. A wooden door made of 4-in. tongued and grooved timber was placed in each bulkhead. When closed the doors press against rubber gaskets to prevent leakage. The lock was supplied with large valves so that it could be filled or emptied in about one minute. The ordinary air pressure was about 5 lbs., and it was found that this was sufficient

to keep the tunnel dry and to give a good supply of fresh air to the workmen. When soft spots occurred in the excavation the pressure was run up to about 9 lbs. A higher pressure than this might have caused a "blowout" as the hard material in the roof of the tunnel was not particularly thick.

The shield, a section through the center of which is shown in Fig. 13, was constructed of ¾-in. steel, and had a total weight of about 16 tons. The shield was 4 ft. long and 16½ ft. in diameter. The upper half was provided with a follower, 7 ft. long, made of ¾-in. steel, bolted to the shield. When the roof was of hard material the "follower" was pulled off the brickwork about 2½ ft. The shield was pushed forward by 12 hydraulic jacks, 5ins. in diameter and 26 ins. long. The water is conveyed to the jacks by a pipe line containing a swinging joint in the shape of an inverted "V" with the joint at the apex, which allowed the shield to be shoved ahead and pulled the pipe with it. The average pressure used in shoving the shield was about 700 lbs. per sq. in., but the pump could develop a pressure of 6,000 lbs.

The material excavated was principally a hard, dry quicksand, at times mixed with clay. All material was handled in cars of a 1 cu. yd. capacity, the cars being pushed in and out by the laborers.

The method of excavation was as follows: The miners excavated about 2 ft. in advance of the shield, the pressure was then applied and the shield shoved ahead into the part just excavated. At the beginning of each day's work the heads of the jacks stood about 1 ft. from the brickwork. Large wooden blocks were then placed against the two outer rings of the brickwork and other blocks were placed between these and the heads of the jacks. The pressure transmitted to the brickwork did not damage it. After the first shove of 2 ft., the jacks were forced back and more blocking placed between them and the other blocks.

The sewer for part of the time, at least, was constructed at the rate of 9 ft. a day or about 250 ft. a month. An additional foot a day could easily have been made but the contractor did not care to take too great chances by pulling the shield follower off the brickwork any further.

Two brick layers laid up the 9 ft. of sewer in about 8 hours, each man laying about 5,000 bricks. The mortar was mixed in the tunnel at the face of the work. In each lineal foot of sewer there were 8 cu. yds. of excavation and 2.62 cu. yds. of masonry, or about 1,100 bricks per lineal foot.

The work was divided into four shifts, the wages and number of the men in each shift being as follows: the superintendent's were the contractor's sons, their wages being estimated at $5 per day:

1 Head Miner at $4.00	$ 4.00
3 Miners at $3.50	10.50
2 Muckers at $2.50	5.00
1 Double Team at $5.00	5.00
Total	$ 24.50

	Second Tunnel Gang, 7 A. M. to 3 P. M.:	
	Same number as first gang	$ 24.50
	Total for tunnel gangs	$ 49.00
	Brick Shift, 3 P. M to 10 P. M.:	
2	Bricklayers at $8.00	$ 16.00
4	Tenders at $1.75	7.00
2	Car Pushers at $1.75	3.50
	Total	$ 26.50
	Top Gang, 7 A. M. to 5:30 P. M.:	
4	Laborers at $1.50	$ 6.00
	Day Shift, 7 A. M. to 7 P. M.:	
1	Superintendent at $5.00	$ 5.00
1	Engineer at $3.25	3.25
1	Fireman at $1.75	1.75
1	Carpenter at $2.00	2.00
4	Car Pushers at $1.75	7.00
1	Car Dumper at $1.75	1.75
	Total	$ 20.75
	Night Shift, 7 P. M. to 7 A. M.:	
1	Superintendent at $5.00	$ 5.00
1	Engineer at $3.25	3.25
1	Fireman at $1.75	1.75
4	Car Pushers at $1.75	7.00
1	Car Dumper at $1.75	1.75
	Total	$ 18.75
	Total labor for 24 hours	$121.00

The two tunnel gangs worked 8 hours each, and the total wages paid them were $49 for 16 hours, during which time they excavated 9 lin. ft., or 72 cu. yds. Hence their labor cost $5.44 per lin. ft., or 68 cts. per cu. yd.

The two top gangs worked 12 hours each, and their total wages were $39.50. In addition to this there was the fuel for a 60-hp. boiler, which could not have exceeded 4 tons in 24 hours, and, doubtless, was much less. Assuming 4 tons at $3, we have $12 to be added to the $39.50, making $51.50, or $2.15 per hour. In the 16 hours of excavating work, the cost of the top labor and fuel would be 16 x $2.15 = $34.40, which is equivalent to $3.82 per lin. ft. of tunnel, or 48 cts. per cu. yd. The total cost of excavation was, therefore, $0.68 plus $0.48, or $1.16 per cu. yd., exclusive of interest and depreciation of plant.

The brick mason gang worked 7 hours, and the total wages were $26.50. Since 2.62 cu. yds. of brick masonry were laid per lin. ft., there were 23.6 cu. yds. laid each shift, the advance being 9 lin. ft. Hence the cost of labor was $1.12 per cu. yd., of $3 per M, or $2.95 per lin. ft. But this does not include the wages and fuel charged to the surface gang, which is $2.15 per hour, or $17.20 for 8 hours. Distributing this $17.20 over the 23.6 cu. yds. of brick masonry we have 73 cts. per cu. yd. of masonry, or $1.91 per lin. ft. of tunnel. The total labor cost

of brick masonry is, therefore, $1.12 plus 0.73, or $1.85 per cu. yd. We are now able to approximate the cost of the tunnel per lineal foot.

	Per lin. ft.
8 cu. yds. excav., underground labor, at $0.68	$ 5.44
8 cu. yds. excav., surface labor, at $0.48	3.82
2.62 cu. yds. brickwork, underground labor, at $1.12	2.95
2.62 cu. yds. brickwork, surface labor, at $0.73	1.91
1,100 bricks at $9 per M	9.90
2.1 bbls. cement (1:3 mortar) at $1.70	3.57
1 cu. yd. sand at $1.00	1.00
Plant, 50 per cent of first cost, distributed over 1,625 lin. ft.	5.00
35 ft. B. M. floor of tunnel at 3 cts.	1.05
Shafts or manholes	1.00
Total	$35.64

The plant is estimated to have cost about $16,000, including $3,000 for track rails, pipe, wire and lamps; and we have assumed that half of this $16,000, or $8,000 should be charged to the 1,600 lin. ft. of tunnel, which is $5 per lin. ft.

The tunnel was temporarily floored with plank, and upon this the tracks were laid. We have estimated that this flooring need not have exceeded 35 ft. B. M. per lin. ft. of tunnel.

No data are available for accurately estimating the cost of shafts, but it is safe to assume $1,600 for the 1,600 ft. of tunnel as the cost of shafts.

It will be remembered that the above costs are based upon a progress of 9 lin. ft. per 24-hour day. Very bad material might reduce progress to 6 ft. per day, correspondingly increasing the cost of labor.

The contractor's plant on this tunnel work was as follows:

2 boilers, 60 hp., return flue, only one in use at a time.

1 Duplex feed pump, 4-in. steam cylinder, 3-in. water cylinder, 5-in. stroke, made by Laidlaw & Dunn, Cincinnati, O.

1 straight line air compressor, class "A," 16-in. steam cylinder, 16¼-in. air cylinder, 18-in. stroke, made by Ingersoll-Rand Co., New York City.

1 vertical high speed engine (20 hp.) for dynamo, cyl. 8 x 10 ins.

1 dynamo with rheostat, capacity 250 incandescent lights, 110 volts, 55 amperes.

1 Norton voltmeter and switches.

1 high pressure hydraulic pump, 10-in. steam cylinder, 1-in. water cylinder, 12-in. stroke, made by the National Pump Co., Chicago.

1 hoisting engine, double cylinder, 8 x 10 ins., with one drum (22 x 22 ins.), sink motion reverse, made by J. S. Mundy, Newark, N. J.

1 pump shaft, steam cyl., 5¼ x 4 ins., made by Knowles Steam Pump Co., 114 Liberty St., New York.

1 elevator cage and guides.

12 hydraulic jacks (5 x 26 ins.), with valves, for shield.

1 shield, weight 32,000 lbs.

In conclusion it should be said that this work was done without the slightest settlement of adjacent buildings, although a 3-story brick building was with a few feet of the line of the sewer.

The contractor was Mr. John Wagner, of Cleveland, O. Mr. J. M. Estep was Assistant Engineer Intercepting Sewers, and to him we are indebted for the data upon which the above given costs are based.

Cost of Sewer in Tunnel, Cleveland, O.*—The tunnel construction is a portion of the contract for the Lakeside Ave. intercepting sewer, between E. 40th and Marquette streets in Cleveland, Ohio, Mr. Thomas W. Nicholson, contractor. For some of the intercepting sewer, brick, with internal diameter of 18 ft. 6 ins., approximate depth to bottom of sewer 40 ft., the price per lineal foot in open cut was $88. In spite of all the care taken by the contractors to brace the trench it broke away from them in places until at some spots the sinking of the street extended to the curb lines. Much trouble was experienced with settlement of buildings with the drawbacks incidental to such happenings. The contractors were in so much trouble that they were permitted to tunnel and no more trouble was experienced with buildings settling and there was an immediate reduction in the cost of the work.

The sewer now being put in by Mr. Nicholson was let to him for $33 per lineal foot when using three rings of brick with wood backing, his price for four rings of brick without the wood backing being $36. There were a number of other bidders who all bid higher for the wood backing form of construction, than for the four rings of brick, internal diameter of the sewer 12 ft. The work is now in progress. It may be interesting to note that on Aug. 4, 1908, a contract was let for another section 3,430 ft. long, to John Wagner, the internal diameter being 12 ft. 3 ins. at a price of $32.73 with wood backing and $33.73 for all brick. The cost to the city is thus less than half by tunnelling compared with the open cut work and the dangers supposed to be guarded against by open cut work are really less with the tunnel. On his present contract for the 12-ft. sewer Mr. Nicholson is said to be meeting with no trouble by reason of settlement of buildings.

To get rid of water and prevent settlement by a too rapid unwatering of the ground, the tunnel is constructed under air pressure of about 7 lbs. to the sq. in. Men work in this pressure for a whole shift, the work being continuous in 8-hour shifts. A shield is used and an attempt is made to complete a 12-ft. length in each shift. The table given shows the progress made during August and September, up to the time the tunnel was visited.

**Engineering-Contracting*, Oct. 6, 1909.

The material being a fine joint clay is shaved by knives. These knives are made like a carpenter's draw knife, or shave knife, with the blade bent to a half circle. Small ones can be used by one man but in this tunnel the air makes the clay dense and several men pull on the knives, thus being enabled to take off long slices. When 2 ft. of excavation are gained the shield is driven ahead, and the wood lining put in. This wood lining consists of blocks of wood about 2 ft. long, 8 ins. wide and 6 ins. thick. On one side a curved piece is cut so the face of the block is cut to a radius of 7 ft. 1 in. The piece removed is nailed on the back and thus the block is 8 ins. wide and 6 ins. thick but front and back both curved to a radius. The excavation is 38 ins. larger than the interior diameter of the sewer and the wooden blocks are used to line the entire excavation, making a wooden ring with the inside face 13 ins. larger than the sewer. The jacks of the shield press against this wood lining and the pieces being cut to fit, any pressure exerted on the side of the excavation will simply force the ends of the blocks together and no other bracing is required. This leaves the space clear for the brick masons.

The masons lay three rings of brick on the wooden ring for one-half the height. Great care is taken to insure grade and as the excavation, if anything, is usually slightly in excess, the extra space is filled with cement mortar. The inside diameter of the sewer is therefore true. When the sewer is completed on either side to the middle, braces are spiked to the ends of the ties of the material track and leaning against the sides of the sewer. Upon the upper ends of these braces are placed heavy timbers carefully leveled and resting upon these timbers are placed semi-circular steel centers made from 4 in. channels, with feet riveted to them to enable them to be maintained in a vertical position. These centers are placed 4 ft. apart and the total length of brickwork put in on a shift is generally 12 ft., requiring three centers. The space between the brickwork and the centers is sufficient to permit the placing of 2 in. lagging on the centers.

Against the lagging the masons lay the brick horizontally on the sides, presenting the narrow edge to the inside of the sewer. The three rings are thus laid and if any spaces exist between the brick and the wooden lining it is easy to slush them in. At the top, arrangements are made to place lagging for 3 ft. across, instead of lengthwise, and thus 1 ft. at a time can be built and cavities taken care of. Brick and mortar are carried in by cars drawn by a mule on ordinary industrial track. Double lines of track are laid with frequent switches and cross overs. All the excavated material is taken out on these tracks and the brick and other materials brought in. There is one shaft from which work is carried in two headings but only one heading was being worked at the time of the visit. The equipment at the shaft head consists of a hoisting engine and air compressor and in the tunnel is a pump to force out the water when it becomes troublesome. The air lock is at the foot of the shaft and about 25 ft. long. The

tunnel was in about 2,000 ft. when visited and under air the whole length.

A usual working force consists of 11 men, according to the city sewer inspector, divided about as follows:

Miners	6
Men placing blocks	2
Muckers	2
Mule driver	1
Total	11

This exact division is not adhered to as all the men help the miners except when blocks are to be placed, when some of the laborers are detailed for that work. There are generally two masons with four or more helpers.

The men are paid by the shift and the inspector did not know what they were paid but from conversation with the men he gathered that the rates of pay are about as follows:

	Per hours.
Masons	$1.00
Helpers	0.25
Miners	0.30
Laborers	0.25

The following table is copied from the inspectors daily reports and collected for each week from tables prepared in the office of the city engineer. It will be noted that the laborers' hours are lumped, regardless of the work performed, no distinction being made between miners, muckers and helpers.

Engineers from the sewer department go into the sewer daily to keep up the line and grade points. For grade, nails are driven in each side at a definite height at intervals, and strings are stretched from nail to nail across the sewer when the men want to check their grade at any time. Upon the strings pieces of paper are hung and sights are taken across two or more strings. In this way it is easy to keep it almost exactly on the grade with the work. Owing to soft places encountered from time to time in the material, it is more difficult seemingly to preserve the line than the grade. The alignment, however, seemed excellent and the work was creditable to the contractor and the men in charge for the city.

Week	Hours					Feet
ending.	Foreman.	Engineer.	Masons.	Helpers.	Laborers.	of sewer completed.
Sept. 18	96	96	112	560	1,647	69
Sept. 11	84	84	80	400	1,210	51
Sept. 4	84	84	24	80	406	18
Aug. 28	168	168	154	800	2,470	97
Aug. 21	168	168	160	800	2,398	111
Aug. 14	168	168	160	800	2,910	101
Aug. 7	168	168	192	960	2,904	124
Total	936	936	882	4,400	13,945	571

The cost was as given in Table XI.

TABLE XI.—LABOR COSTS PER FOOT OF SEWER.

Week ending.	Foreman.	Engineer.	Masons.	Helpers.	Laborers.	Total labor cost per foot.
Sept. 18...	$0.68	$0.56	$1.62	$2.03	$6.56	$11.45
Sept. 11...	0.82	0.66	1.57	1.96	6.52	11.53
Sept. 4....	2.33	1.87	1.33	1.11	6.20	12.84
Aug. 28...	0.87	0.69	1.59	2.06	7.00	12.21
Aug. 21...	0.76	0.61	1.44	1.80	6.59	11.20
Aug. 14...	0.83	0.67	1.58	1.98	7.92	12.98
Aug. 7....	0.68	0.54	1.55	1.93	5.71	10.41

The wages are assumed to be correct as given by the inspector. The wages for laborers are assumed at an average of 27½ cts. per hour; foreman assumed 50 cts. per hour; engineer assumed at 40 cts. per hour. This analysis is made upon the foregoing data solely and has not been checked with information from the contractor.

The foregoing labor cost takes the wood, brick, mortar, etc., down into the tunnel; puts them in place and the excavated material is brought to the surface to be hauled away. This hauling must add $2 per foot to the cost unless some arrangements are made to dispose of the material at a profit.

Each foot of excavation contains 6.7 cu. yds. In each foot there are 800 brick and 276 ft. B. M. of lining blocks. The mechanical equipment consists of a shield, a hoisting engine, air compressor and two pumps; one in each heading and of tracks for cars, cars, mules, piping, etc., and locks. For this equipment and operation a charge of $1.25 per foot should be reasonable as it will not be worn out on this one job.

The following estimate should be about right for similar work:

Plant, fuel, etc.	$ 1.25
800 brick at $15 per M.	12.00
Mortar	1.28
Wood lining, 276 ft. B. M. at $35	9.63
Hauling away material	2.00
Cost per foot exclusive of labor	$26.16

The labor costs vary as shown from $10.41 to $12.98 per foot, which brings the cost per foot from $36.57 to $39.14, the contract price being $33.

When both headings are going the cost for foreman and engineer will of course be divided but this will cut off less than $1 per foot. If the excavated material is sold the price cannot more than pay the cost of hauling. Assuming everything favorable that can be assumed, it looks as if the contract is not going to be very remunerative.

The men lumped together as laborers handle all the material into and out of the tunnel, do the mining, cleaning up, assisting brick masons, helpers, etc., so the actual excavation cost is less than $1 per cu. yd. The cost of masons and helpers is about $2.80 per 1,000 brick. No fault can be found with these items.

Labor Cost of a Large Brick Sewer in Chicago.*—In 1901 the

*Engineering-Contracting, May 30, 1906.

City of Chicago began the construction of the south arm of its intercepting sewer system, comprising Section G, which extended from 39th street to 51st street, and Sections G 3 and H, which extended from 51st street to 73d street. The work was done by day labor under the supervision of the city's engineers. Descriptions of the methods and cost of driving sheet piling and of the excavation for these sewers were given in the March and April issues of this magazine.

The specifications for the brickwork on Section G called for five rings of hard burned sewer brick, laid in natural cement mortar, composed of one part cement and one part sand. From 39th street to 44th place, the sewer was 16 ft. in internal diameter, and from 44th place to 51st street, it had an internal diameter of 15¼ ft. Bricklaying on Section G was commenced in the early part of June, 1901, and was completed about March 1, 1903, no work being done during the winter of 1901-2. On account of the necessity of getting through the freight yards of the Illinois Central Ry. at 51st street, bricklaying was carried on during the winter of 1902-3 when the weather would permit. At no time was brick laid when the temperature was lower than 15 degrees above zero. The best quality of torpedo sand, thoroughly heated was used in the mortar. This section of the conduit was about 300 ft. long.

The brick were unloaded from the cars and placed in piles about 16 ft. from the side of the trench. From these piles the bricks were loaded and wheeled to the side of the trench, and were then delivered to the bricklayers by means of tossers working on the bank and on scaffolds on the braces. All cement mortar was mixed by hand and lowered in galvanized iron pails by means of ropes, from scaffolds on the top set of braces.

During the season of 1901, eight bricklayers were employed, and an average of about 22 ft. of conduit was built per day. This was equivalent to about 40.5 cu. yds. of brickwork per day, or 5 cu. yds. per mason. The second year, 13 bricklayers were used, and they averaged about 35 ft. of conduit per day. It should be remarked that while 13 bricklayers were carried on the roll at this time, the gang usually consisted of 12 men. The gang for handling brick, mixing cement, etc., consisted of from 70 to 75 men for 12 bricklayers.

On the construction of that portion of the intercepting sewer lying between 51st street and 73d street, the first brick was laid Dec. 8, 1901. But 144 ft. were finished that year owing to the cold weather. Construction was resumed about March 15, 1902, and continued until Jan. 2, 1903, when it was stopped for the winter. The work was resumed April 10, 1903, and was completed July 10. The masonry consisted of five concentric rings of brick laid in natural cement mortar, composed of one part cement and one part sand. From 51st street to 56th street the sewer was to have an internal diameter of 14¼ ft.; from 56th street to 63d street the diameter was 13½ ft.; from 63d street to 70th street,

13¼ ft., and from 70th street to 73d street, 12½ ft. The excavated sections were 48 ft. long, and consequently 12 bricklayers were employed most of the time. The work was so arranged that as soon as the invert was finished, work was begun on the arch. The arch work was usually kept at least one day behind the invert in order to give plenty of room for setting up centers, removal of timbers, and at the same time keep the mason gang busy, if there should be any delay in excavating the bottom or from other causes.

Brick were delivered in cars on the street by the Municipal narrow gage railway, no hand wheeling being necessary. When dumping space was available, sufficient brick for half the invert were usually on the bank before the masons began to work. The brick were passed from hand to hand to the masons.

As in the construction of Section G, the cement was mixed by hand, the mixing being done as close to the workers as possible, but on the opposite side of the trench from the brick pile. The mortar was lowered by hand, one man supplying three masons, that number being allotted to each 12-ft. section. The division was made on account of the Potter trench machine bents, which were so low that a man could not pass under them while on the cement platform. The cement platform was laid on the cross timbers which supported the trench machine. The platform was about 1 ft. above the street surface, thus making a lowering distance of from 22 ft. to 28 ft. when mortar was delivered for the invert. A departure was made from the usual custom of having the mason tender dump the mortar, in that one man in the bottom was assigned to do this work. This proved a decided advantage as the mortar boxes were always kept filled. It might be well to note here that while a mason tender could have handled the mortar for a part of the time, yet even a delay of a few minutes for one mason at frequent intervals, amounts to considerable at the end of the day. Every contractor knows that a slight excuse for slow work will make a considerable difference in the amount of finished product.

When 12 masons were working the mason gang consisted of from 58 to 65 men. The gang included masons, tenders, brick tossers and cement handlers. With this force, from 38 to 44 ft. of completed sewer were built daily.

The mason gang was as follows:

	Rate.	Per Day.
1 Foreman	$10.00	$ 10.00
12 Masons	9.00	108.00
11 Bottom tenders	3.25	35.75
7 Bank men	3.50	24.50
7 First scaffold men	2.50	17.50
7 Second scaffold men	2.50	17.50
7 Third scaffold men	2.75	19.25
6 Cement mixers	2.75	16.50
5 Cement carriers	2.75	13.75
5 Cement lowerers	2.75	13.75
2 Wheelers	2.50	5.00
5 Sand men	2.50	12.50
3 Laborers	2.50	7.50
Total per day		$301.50

As an average of 38 ft. of sewer was built each day, the labor cost per foot is about $7.93. Assuming that the inside diameter of the sewer was 13½ (some sections were 14¼ ft., 13¼ ft. and 12½ ft.) the labor cost for the brick masonry amounted to $2.48 per cu. yd.

It will be noticed in the above tabulation that the rates of wages in many cases were excessive. All that it is necessary to say in regard to this is that the work was done by the city.

Cost of a Concrete and Brick Sewer.—Mr. William G. Taylor, City Engineer of Medford, Mass., gives the following data of work done in 1902, by day labor, for the city. Figure 14 is a cross-section of the sewer, which has a concrete invert and sides and a brick arch. The concrete was 1 : 3 : 6 gravel. The forms for the invert were made collapsible and in 10-ft. lengths. The two halves

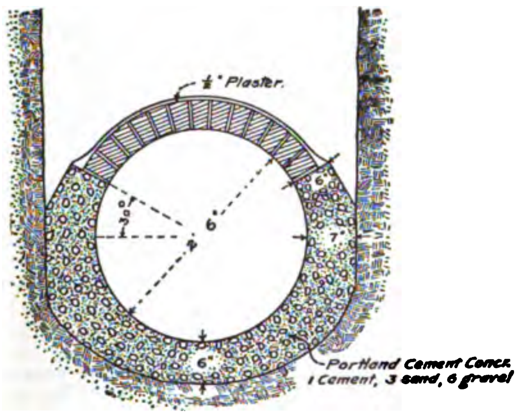


Fig. 14.—Concrete and Brick Sewer.

were held together by iron dogs or clamps. The morning following the placing or the concrete the dogs were removed and turnbuckle hooks were put in their places, so that by tightening the turnbuckle the forms were carefully separated from the concrete. The concrete was theen allowed to stand 24 hrs., when the arch centers were set in place. These centers were made of ⅞ x 1½-in. lagging on 2-in. plank ribs 2 ft. apart, and stringers on each side. Wooden wedges on the forward end of each section supported the rear end of the adjoining section. The forward end of each section was supported by a screw jack placed under a rib 2 ft. from the front end. To remove the centers, the rear end of a small truck was pushed under the section about 18 ins.; an adjustable roller was fastened by a thumb screw to the forward rib of the center; the screw jack was lowered allowing the roller to drop on a run board on top of the truck; the truck was then pulled back by a tail rope until

the adjustable roller ran off the end of the truck; whereupon the truck was pulled forward, drawing the center off the supporting wedges of the rear section. In this manner not the least injury was done to the fresh concrete.

Each lineal foot of sewer required 1¼ cu. yds. of excavation; 4 cu. ft. of concrete, and 1 cu. ft. of brick arch. The sewer was 1,610 ft. long and was built by day labor, wages being $2 for 8 hrs. The material excavated was gravel and clay.

	Per cu. yd.	Per lin. ft.
Excavation and backfill:		
Excavation, labor, 25 cts. per hr.	$0.339	$0.424
Bracing	0.026	0.032
Backfilling	0.168	0.210
Waterboy	0.017	0.021
Kerosene	0.009	0.011
Lumber	0.035	0.044
Total	$0.594	$0.742
Concrete masonry:	Per cu. yd.	Per lin. ft.
Portland cement, at $2.15 per bbl.	$2.292	$0.343
Labor mixing and placing	3.017	0.452
Cost of forms	0.187	0.028
Labor screening gravel*	0.471	0.070
Carting	0.592	0.088
Miscellaneous	0.146	0.021
Total	$6.705	$1.002
Brick masonry:	Per cu. yd.	Per lin. ft.
492 brick, at $8.50 per M	$ 4.182	$0.153
1⅓ bbls. cement,† at $2.25 per bbl.	3.026	0.111
Forms	0.408	0.015
Labor, mason	1.343	0.049
Labor, helpers	2.091	0.077
Carting	0.680	0.025
Incidentals	0.340	0.012
Total	$12.070	$0.442

*The gravel and sand were obtained from the excavation.
†This includes cement used in plastering the arch.

The cost of this 30-in. sewer was, therefore, $1.44 per lin. ft., exclusive of the excavation which cost 74 cts. per lin. ft. The cost of brickwork in manholes was $15.34 per cu. yd. It should be noted that wages were high ($2 per 8 hrs.) and that the work was done by day labor, thus making the cost higher than it would be to a contractor.

Cost of a Concrete Sewer.*—The work consisted of a sewer 1,360 ft. long and 30 ins. inside diameter, with a 4-in. shell, constructed during November and December, 1908, with the thermometer ranging 15 degrees above zero to above freezing point. The necessity of using frost preventives added about 2½ cts. per lin. ft. to the cost of the work. The following is a description of the sewer and its construction. The location of the work was at Fond du Lac, Wis.

About four years ago the city dug an open drain along a highway upon the outskirts of the city for carrying storm water into

*Engineering-Contracting, Jan. 27, 1909.

De Neveu creek. On account of the ditch washing into the road it was decided to place a pipe in this trench and backfill over it. The contract was awarded to Burett & Dooley for a monolithic concrete sewer.

It contained about 1/9 cu. yd. of concrete per lineal foot. In addition there were 17 cu. yds. of concrete in the two abutments or portals at the ends of the sewer.

The itemized total cost of the sewer was as follows:

Items.	Total.	Per lin ft. Cts.
Labor	$635.50	46.72
Tools	24.59	1.81
Sandy gravel	208.40	15.32
Lumber	14.04	1.03
Water	11.35	0.83
Frost preventives	34.38	2.53
Cement	370.19	27.22
Steel forms	204.35	15.02
Engineering	132.00	9.71
Totals	$1,634.80	$1.20

In this statement the labor item is for unskilled laborers at $2 per day, working from 3 to 14 men a day for 29 days and 2 foremen at $3 each for 31 days. The cost items for tools, lumber and frost preventives are the differences between their purchase prices and what they brought when afterwards sold. The sandy gravel was purchased delivered from three different pits at $1.50 per load of about 1.75 cu. yds., with some at 10 cts. extra per load; it cost, therefore, about 89 cts. per cu. yd. The gravel was mixed to obtain the greatest density of aggregates, and 5 parts of gravel were mixed with 1 part cement to make the concrete. The cement cost $1.70 per barrel delivered in sacks, less the rebate on sacks returned. Water cost for hauling only 35 cts. per load. The lumber was used for abutment forms and for establishing grades. The frost preventives consisted of horse stable manure, marsh hay, and a thin layer of flax straw sewed between two sheets of rosin paper and also fuel for heating the concrete materials. The steel forms were rented and the cost includes drayage to and from the job and a small sum for oil to grease them. The charge for engineering covers the entire expense to the city and township for plans, specifications, advertising, inspection of sewer during construction, etc.

Separating the abutments containing 17 cu. yds. of concrete the cost was as follows:

Items.	Total.	Per cu. yd.
Labor	$25.50	$ 1.50
Tools	00.59	0.035
Gravel	15.00	0.882
Cement	32.01	1.882
Lumber	40.04	0.237
Water	00.60	0.035
Frost preventives	1.88	0.110
Centers	0.75	0.045
Engineering, etc.	5.00	0.295
Totals	$85.37	$5.021

Some of these items are actual amounts and others are close approximations. The costs for the sewer proper arrived at in the same manner were as follows:

Items—	Total.	Per Lin. Ft.	Per Cu. Yd.
Labor or concrete	$253.00	$0.187	$1.683
Labor excavation	357.00	0.263	2.367
Tools	24.00	0.017	0.153
Gravel	193.40	0.142	1.278
Lumber	10.00	0.007	0.063
Water	10.70	0.008	0.072
Frost preventives	32.50	0.024	0.216
Cement	338.18	0.249	2.241
Center molds	203.60	0.149	1.341
Engineering	127.00	0.093	0.837
Totals	$1,549.43	$1.139	$10.251

In the above table the amount for the concrete labor includes the labor cost for heating the materials, mixing and depositing the same in position complete, also for the small expense of operating the steel forms. The rest of the labor expense was for excavating the trench an average depth of 3 ft. and for back filling. This was done, as noted previously, in an old ditch, the bottom of which was red clay soil, requiring but a slight expense for trench bracing. No water ran in the trench except on a couple of days it rained when the water ran out soon through the molds into the sewer.

Flax straw, bound in paper, already put up, was tried as a cover to the fresh concrete pipe, to keep frost away while the cement was setting, but the vapor from the concrete softened the paper cover so that it could not be handled and the article had to be discarded. The horse stable bedding of straw proved to be efficient for keeping frost out of the green concrete, it generating a certain amount of heat and allowed the moisture to pass through it from the heated concrete. Due to the chemical changes going on in this cover, too strong an article should not be laid next to fresh concrete, as in some places on the pipe it was observed that the cement did not set well for a depth of 1/16 to ⅛ in. A thin layer of marsh hay was placed between the manure and the concrete on the balance of the work and the condition did not appear again.

In the steel forms lighted oil heaters were placed at short intervals to keep up summer conditions while the cement made its initial set.

The style of the centers used was the full circle form so that the crown and invert of the pipe were built in one operation. The materials were mixed on a flat No. 12 gage steel sheet, size 60 x 156 ins. Concrete was put in the bottom of the trench first, which was dug somewhat rounding, and graded 4 ins. thick. Strips of No. 26 gage sheet steel 12 ins. wide by 8 ft. long, previously rolled to the arc of 30-in. circle, was next laid, one piece lengthwise on this bed, then one 5-ft. section of steel forms was placed upon the strip, or track. The form was expanded to size by turning the hand wheel, the correct diameter being obtained by fitting a wire hoop

gage around the near end of the center and expanding the center against the gage. Another batch of concrete now ready was positioned around the form, an operator at the front end of the form having a steel blade, 5 ins. wide by 10 ins. long, affixed to a long handle, tamped the concrete firmly to place under the two bottom quarters of the form so that the possibility of voids or pockets forming in the bottom of the concrete pipe to be refinished later was eliminated, the concrete being positioned on top of the

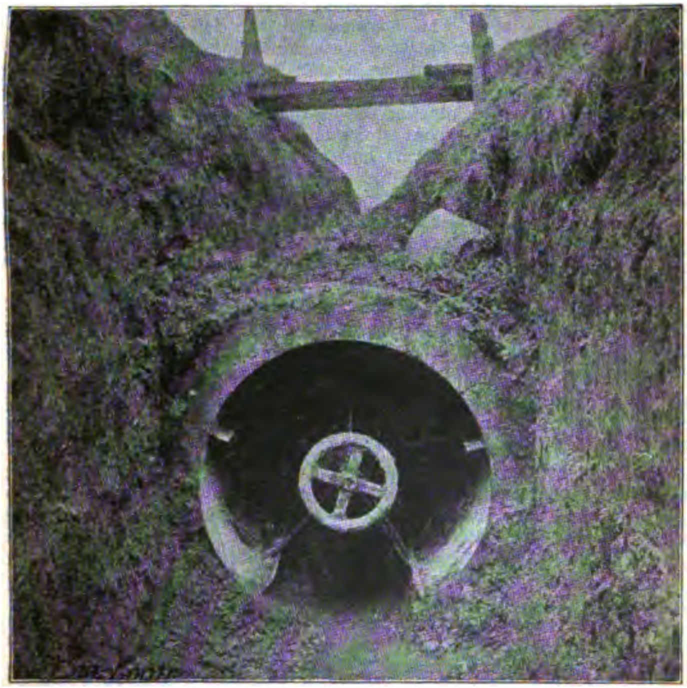


Fig. 15.—Centers for Concrete Sewer.

form nearly out to the end. Another form being set, the process described was repeated.

The object of using a light steel track, or slide, under the forms, was so that the molds could be drawn out easily the next morning one at a time, and to prevent scraping out partially set concrete from the bottom of the sewer, the steel track being laid with lapped ends so that the forms could slide over the joints and not disturb the track. The track was, of course, taken each

morning from the sewer after the centers were withdrawn and used repeatedly.

Collapsing of the centers was accomplished by merely giving the hand wheel a few turns to the left, when the mold was pulled out of the sewer with a rope and taken ahead in the trench for resetting when needed. No bracing of the forms was required to keep them in alignment. The top of the concrete pipe was shaped with a wood hand float, the concrete for this purpose not being made wet enough to make it sloppy.

The adjustable steel centers as used on this job were handled on the desirable unit plan; however, all the forms may be set before placing concrete about them, or in any other way that may appeal to a contractor as most advantageous. Two Y-connections were made to this sewer by placing the small ends of clay pipes against the steel forms as the concrete was being positioned. The next morning when the steel forms had been removed the first connection had some concrete to be broken out of the end and refinished, while the one made later was found perfect. Gas engine oil thinned with kerosene and applied with a brush to the surface of the molds prevented the adhesion of concrete to the forms. The temperature varied during construction when concrete was made from 15° above zero to above the freezing point. The thermometer one morning registered 12° below zero, but by 10 o'clock it showed 15° above when concreting was started. One foreman with a crew of six men often put in 70 ft. of sewer in less than 5 hours' time.

The style of mold used on this job is patened by J. E. Dooley, and is manufactured by the Adjustable Steel Centering Co. of Fond du Lac, Wis. We are indebted to the contractors, Burett & Dooley, for the information from which this article has been prepared.

Cost of Reinforced Concrete Sewer at Cleveland, O.—Mr. Walter C. Parmley, M. Am. Soc. C. E., gives the following data: There were 3½ miles of reinforced concrete sewer, 13½ ft. diameter, of section shown in Fig. 16, and 12 ins. thick at the crown. The contract price was $62 per lin. ft., including excavation, and the excavation averaged 20 cu. yds. per lin. ft. The bid for a brick sewer was $75 per lin. ft.

It will be noted that there are two rows of "anchor bars" buried in the side walls. The invert and side walls were first built up as high as the top of the brick lining, then the arch centers were placed, and the steel skeleton was bolted to the anchor bars. The ribs of this steel skeleton were spaced 15 ins. centers, and there were 8 rows of horizontal or longitudinal bars of 1½ x ¼-in. steel bolted to the ribs. The metal was all bent to shape in the shop, so that there was no field work except to place and bolt the metal together. There were 93 lbs. of steel per lin. ft. of sewer, of which 56 lbs. made the skeleton in the arch, and 37 lbs. of anchor bars. This design of steel skeleton was patented by Mr. Parmley.

The lagging of the arch centers was covered with building paper water-proofed with paraffine. Then Portland cement mortar 2 to 3 ins. thick was plastered on the paper, so as to form the interior

finish of the arch. Then the concrete for the arch was placed and rammed, being 12 ins. thick at the crown and 15 ins. thick at the spring line. No outside forms were used on the arch. The arch concrete was 1 : 3 : 7½. When the paper lining was pulled off a smooth surface was left. The invert concrete was made with natural cement.

Mr. Parmley had an inspector keep a record of progress for several days on the work, when the men did not know they were being

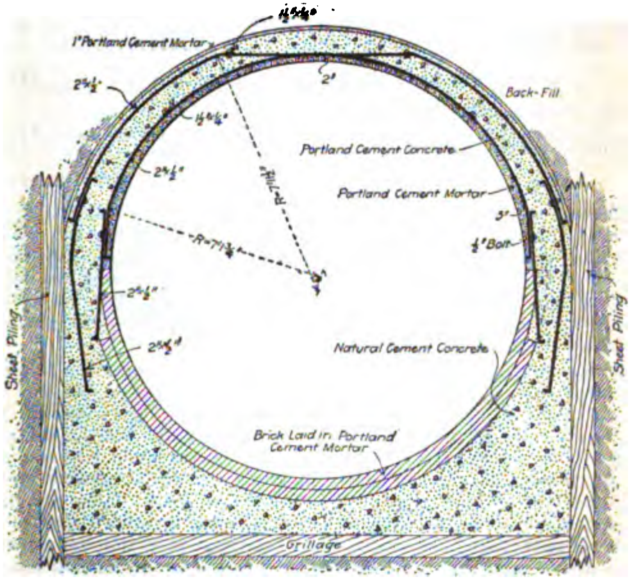


Fig. 16.—Reinforced Concrete Sewer.

timed. He informs me that an 8-hour shift was worked. The labor cost of building 13½-ft. concrete steel sewer was as follows:

Labor placing anchor bars (1,500 lbs.):

1 man 1 day, at $3.50	$3.50
1 man 1 day, at $1.75	1.75
1 man ½ day, at $1.60	0.80
Placing 1,500 lbs. steel, at 0.4 cts.	$6.05

Labor on concrete invert and side walls:

5 men mixing and wheeling, at $1.75	$ 8.75
1 man tamping	1.75
1 man carrying concrete	1.75
⅔ man lowering concrete, at $2.25	1.50
Labor, 13 cu. yds. concrete, at $1.06	$13.75

Labor on shale brick lining (2 rings):

2 masons, at $5.60	$11.20
1 man mixing mortar	2.25
3 men wheeling sand, filling buckets and dumping at $1.75	5.25
⅓ man lowering materials, at $2.25	0.75
Labor, 6.38 cu. yds. brick work, at $3.05	$19.45

Labor on concrete arch:

1 man putting mortar lining on centers, 3 days, at $1.75	$ 5.25
2 men mixing mortar, screening and wheeling sand, 3 days, at $1.75	10.50
8 men on mixing board, 3 days, at $1.75	42.00
1 man tamping, 3 days, at $1.75	5.25
Labor, 72 cu. yds., at $0.87	$63.00

Labor placing centers and steel skeleton:

1 man, 3 days, at $3.50	$10.50
2 men, 3 days, at $1.75	10.50
Labor, 40 lin. ft., at 52½ cts. per ft.	$21.00

There were 56 lbs. of steel skeleton per lin. ft., and about ⅓ the time of this last gang of 3 men was spent in placing the metal, ⅔ being spent in moving and placing the centers; so the labor cost 0.3 cts. per lb. of steel (not including shop work) and the labor moving centers cost 35 cts. per lin. ft. of sewer. The backfilling was begun 6 to 12 hrs. after the arch was built, but the centers were left in place 14 days.

On another section of this sewer a six-day observation showed the labor cost (hand work, no machine mixers) was 81 cts. per cu. yd. of concrete in the invert and side walls, and 70 cts. per cu. yd. on the concrete in the arch; 36 cts. per lin. ft. for placing centers, and 18 cts. per lin. ft. for placing the steel skeleton; 0.32 cts. per lb. for placing the anchor rods. A gang of 2 brick masons and 6 laborers laid 11.2 cu. yds. of the double-ring brick lining per day, at a cost of $2 per cu. yd. All wages were as above given. It will be seen that this longer observation gave much lower costs than above tabulated, and Mr. Parmley regards it as being nearer a fair average.

Cost of Reinforced Concrete Sewer, Wilmington, Del.—Mr. T. Chalkley Hatton, M. Am. Soc. C. E., gives the following data: Fig. 17 shows a profile of Price's Run Sewer, Wilmington, Del., built in 1903, by day labor for the city, the working day being 8 hrs. long. Fig. 18 shows cross-sections at different points. The notable feature is the boldness in the design of such thin concrete shells for sewers of such large diameters. The cross-sections of sewers in trenches deep enough to cover the arch are marked "deep cutting"; the sections where the arch projects above the ground surface are marked "light cutting." The section through the marsh was 700 ft. long, the cutting being 8 ft. deep, and at high tide the marsh was flooded 1 to 4 ft. The material was a soft mud that would pull a tight rubber boot from a workman's foot. The cost of this marsh excavation including cofferdams, underdraining, pumping, etc.,

was $4.60 per cu. yd. For 1,100 ft. the 9¼-ft. sewer was through a cut 22 to 34 ft. deep, the material being clay underlaid by granite. A Carson-Lidgerwood cableway was used. Although the crown of the arch was but 8 ins. thick, it withstood the shock of dumping 1 cu. yd. buckets of earth and rock from heights of 3 to 10 ft.; and the weight of 25 ft. of loose filling caused no cracks in the concrete.

Concrete was placed in 4-in. layers (the depth of the lagging) and well rammed, since it was found that "wet" concrete left small honeycombed spaces on the inner surface. Concrete for the invert was 1:2:6, the stone being 1½-in. and smaller, and the sand being crusher dust. The arch was 1:2:5.

The reinforcing metal used in the 9½-ft. sewer was No. 6 expanded metal, 6-in. mesh, in sheets 8 x 5½ ft., supplied by Merritt & Co., of Philadelphia. A single layer was placed around the

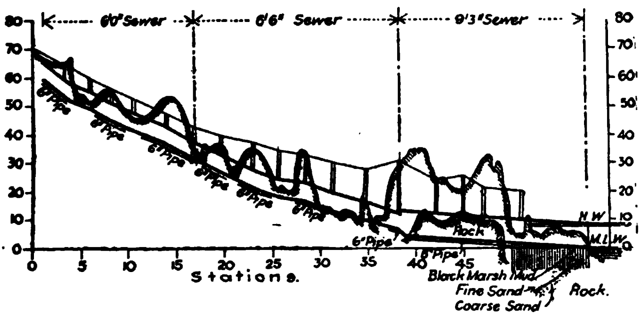


Fig. 17.—Profile of Sewer.

sewer, 2 ins. from the inner surface, its position being carefully maintained by the men ramming, and with but little difficulty as the sheets were first bent to the radius of the circle. Each sheet was lapped one mesh (6 ins.) over its neighbor at both ends and sides, and no sheets were wired except the top ones, which were liable to displacement by men walking over them.

The metal used on the rest of the work was a wire-woven fabric furnished by the Wight-Easton-Townsend Co., of New York. This fabric comes in rolls 5½ ft. wide and 100 ft. to the roll. The wire is No. 8, with a 6 x 4-in. mesh. This fabric was placed by first cutting the sheets to the required length to surround the sewer entirely, embedding it in the concrete as fast as concrete was placed, in the same manner as was done with the expanded metal, except over the center where, on account of its pliability, the fabric was held the proper distance from the lagging by a number of 2-in. blocks, which were removed as the concrete was placed. The wire cloth, being all in one sheet, can be placed a little more expeditiously than expanded metal, but, on the other hand, the

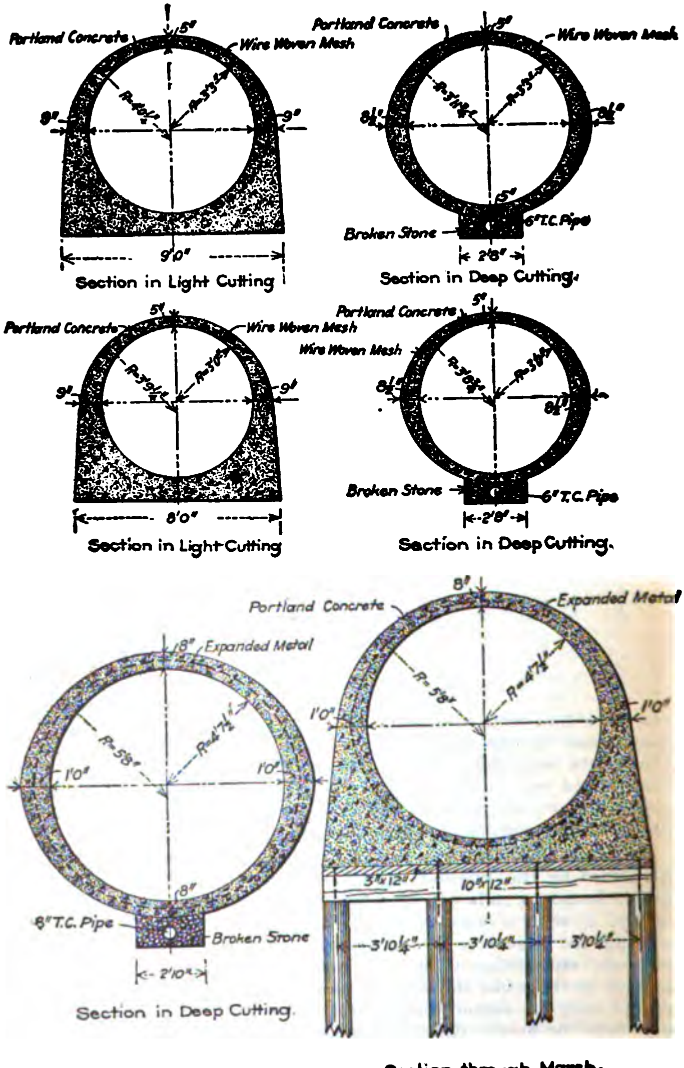


Fig. 18.—Cross Sections of Concrete Sewer.

expanded metal holds its position better in the concrete, since it is more rigid.

I quote now from Mr. Hatton's letter to me: "The major portion of concrete was mixed by machine at a cost of 66 cents per yard, including wheeling to place, coal and running of mixing machine, wages being $1.50 per day of 8 hrs. Stone was delivered alongside of machine and all material had to be wheeled in barrows upon the platform, and after mixing to the sewer. Placing and ramming concrete around the forms cost 39 cts. per cu. yd., additional. Setting forms in invert cost 2 cts. per cu. yd. of invert; setting centers, 7 cts. per cu. yd. of arch. Cost of setting forms and centers includes placing steel metal. Each lineal foot of 9¼-ft. sewer contained 1 cu. yd. of concrete, although the section only calls for 0.94 cu. yd. The excess was usually wasted by falling over sides of forms or being made too thick at crown.

"This yard of 1:2:5 concrete cost in place as follows (record taken as an average of several days' run):

Cement, 1.31 bbls., at $1.30	$1.703
Stone, 0.84 cu. yds., at $1.21	1.016
Stone dust, 0.42 cu. yds., at $1.21	0.508
Labor, at 18¾ cts. per hour	0.987
Labor setting forms and setting metal	0.045
Cost of forms (distributed over 1,800 ft. of sewer)	0.082
40 sq. ft. expanded metal, at 4¼ cts.	1.700
Labor plastering invert	0.070
Cost per lin. ft., or per cu. yd.	$6.111

"The forms for the invert were made of 2-in. rough hemlock boards cut out 4 ins. less diameter than the diameter of the sewer, except for 18 ins. at the bottom of the form which coincided with the inside form of sewer. The bottom of the sewers was laid to the bottom of this form before it was set. Then the lagging, consisting of 2 x 6-in. x 16 ft. hemlock planed, was placed against each side of the form, one at a time, and the concrete brought to the line of this top in 6-in. layers until the whole invert was finished. These forms were set in 16 ft. sections, five to each section.

"The centers consisted of seven ribs of 2-in. hemlock upon which was nailed 1½-in. lagging, 2 ins. wide, tongued and grooved, and were 16 ft. long, non-collapsible, but had one wing on each side, 9 ins. wide, which could be wedged out to fit any inaccuracies in the invert. We used four of these centers setting two at each operation and worked from two ends. We left the centers in for 18 hours before drawing.

The cost of the concrete on the smaller sewers was the same as are the larger sewers, but the steel metal cost less, as it was wire woven metal that cost 2½ cts. per sq. ft. It was much easier handled and cut to no waste as it came in long rolls and was very pliable.

"After training our men, which occupied about one week or 10 days, we had no difficulty in getting the concrete well placed around the metal, preserving the proper location of the latter, which, how-

ever, bore constant watching, as a careless workman would often take the temporary supporting blocks and allow the metal to rest against the wooden center, in which case the metal would show through the surface inside of the sewer. The metal was kept 2 ins. away from the inside forms and the arch. To keep it at this location we had several 2-in. wooden blocks cut which were slipped under the wire or expanded metal and as soon as some concrete was pushed under the wire at this point the block was removed.

"After the forms were removed the invert needed plastering, but the arch was practically like a smoothly plastered wall except where it joined the invert, where it frequently showed the result of too much hurry in depositing the first loads of concrete on the arch. We remedied this by requiring less concrete to be deposited

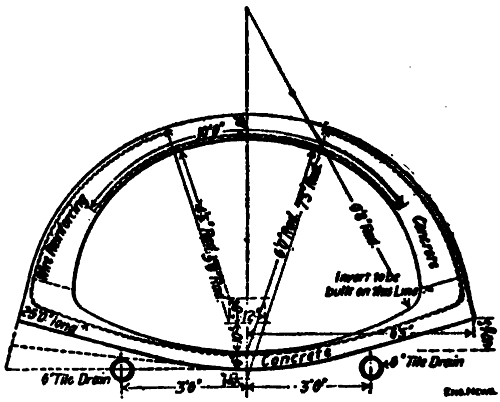


Fig. 19.—Reinforced Concrete Sewer.

at the start, thus giving the rammers time to place the material properly.

"An interesting result was obtained in the smoothness of the inside surface by using a mixture of different sized stones. When ¾-in. stones or smaller were used in the arch, the inside was honeycombed; but, where 1 to 1½-in. stones (nothing smaller) were used, the inside was perfectly smooth, and the same was true of the invert, showing that the use of larger stones is an advantage and secures more monolithic work. When the run of the crusher from 1½ to ¾-in. stones was used the work was not at all satisfactory.

"The difference in cost of mixing by hand and machine is practically nothing on this kind of work, as the moving of the machine to keep pace with the progress of the work equals the extra cost of mixing by hand when the mixing can be done close to the point where the cement is being placed."

The total cost of the sewers, including excavation, etc., was:

	Cost per lin. ft.
9¼-ft. sewer through marsh	$32.00
9¼-ft. sewer in cut averaging 24½ ft.	24.00
6½-ft. sewer in cut averaging 12 ft.	10.00
5-ft. sewer in cut averaging 11½ ft.	6.70

Cost of a Reinforced Concrete Sewer, Kalamazoo, Mich.—Mr. Geo. S. Pierson gives the following data:

A reinforced concrete sewer 1,080 ft. long at Kalamazoo, Mich., was begun Nov. 3, 1902, and finished Jan. 10, 1903. The work was done by day labor for the city. Much of the work was done at a temperature of 12° to 25°. The sewer arch has a span of 9 ft. 10 ins., and the sewer is 6 ft. high from invert to crown. The arch is 8 ins. thick at the crown, and the invert is 6 ins. thick, Fig. 19. The concrete was reinforced with woven-wire fabric of No. 11 steel wires. The concrete was 1 cement to 6 gravel and sand, but this proportion was not strictly adhered to. The centers were built in sections 12½ ft. long, and there were 6 arch sections and 12 invert sections. The ribs for the arch centers were of 2-in. pine, and were 2 ft. apart. The sheeting was 1-in. dressed white pine. The average gang was 10 men mixing and wheeling concrete, 5 men placing and ramming, and 4½ men moving and setting up forms. This gang averaged 18.6 lin. ft. of sewer per day, the best day's work being 28 lin. ft. There were 0.95 cu. yds. of concrete per lin. ft. of sewer. Wages were $1.75 a day. The cost per lineal foot was as follows, including superintendence:

	Per lin. ft.	Per cu. yd.
1.18 bbls. cement	$2.44	$2.56
Sand and gravel	0.42	0.44
Labor mixing and wheeling (10 men)	0.98	1.03
Labor placing and ramming (5 men)	0.47	0.50
Labor moving and setting forms (4½ men)	0.43	0.45
Cost of forms and templates	0.30	0.32
Metal fabric (175 lin. ft. No. 11 wire)	0.39	0.41
Finishing	0.09	0.10
Tools, general expenses and superintendence	0.43	0.45
Total	$5.95	$6.26

The cost of excavation and backfilling is not included

It will be noted that the cost of moving and setting the forms was unnecessarily high. Compare this cost of 45 cts. per cu. yd. with the 5 cts. per cu. yd., at Wilmington, Del., in the next case cited.

Cost of a Reinforced Concrete Sewer at South Bend, Ind.*—In building 2,464 ft. of 66-in. circular reinforced concrete sewer at South Bend, Ind., in 1906, the method of construction illustrated in Figs. 20, 21 and 22 was employed. The sewer has a 9-in. shell buttressed on the sides, and is reinforced every 12 ins. by a 3/16 x 1-in. peripheral bar in the sides and roof and 3 ins. in from the soffit.

*_Engineering-Contracting_, Aug. 22, 1906.

Each bar is composed of three pieces, two side pieces from 15 ins. below to 6 ins. above springing lines and a connecting roof bar attached to the side bars by cotter pins. Two grades of concrete were used, a 1 : 3 : 6 bank gravel concrete for the invert and a 1 : 2 : 4 bank gravel concrete for the arch. The invert was given a ½-in. plaster coat of 1 : 1 mortar as high as the springing lines.

Forms and Concreting.—In constructing the sewer the trench was excavated so as to give a clearance of 1 ft. on each side and was

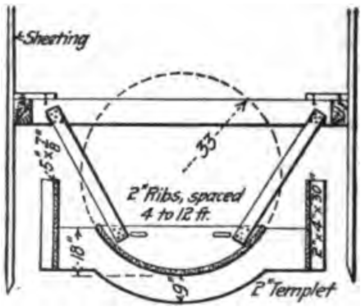


Fig. 20.—Concrete Sewer Construction.

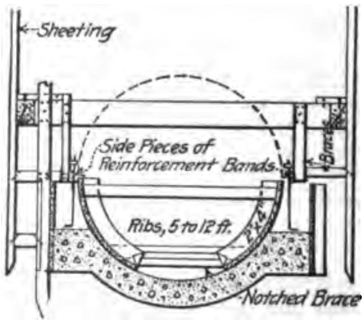


Fig. 21.—Concrete Sewer Construction.

sheeted, as shown by Fig. 20. The sewer was built in 12 ft. sections as follows: The bottom of the trench was shaped as nearly as possible to the grade and shape of the base of the sewer. Four braces to each 12-ft. section were then nailed across the trench between the lowest rangers on the trench sheeting. A partial form consisting of a vertical row of lagging was set on each of the outside lines of the sewer barrel as shown by Fig. 20. Each section of this lagging was held by stakes driven into the trench bottom

and nailed at their tops to the cross braces, as shown by Fig. 21. A template for the invert was then suspended from the cross braces by pieces nailed to the four ribs of the template and to the cross braces, as shown by Fig. 20. The concrete was now placed and carried to the top of the template, which was then removed. The side pieces of the reinforcing bars were then set and fastened, as shown by Fig. 21. The side forms extending up to the springing lines were then placed. They were held in position by braces nailed to their ribs at the tops and by other braces fitting into notches in the ends of their ribs at the bottom. The concrete was then carried up to the springing lines; the arch centers in two pieces were placed; the arch bar of the reinforcement was placed, and the extrados forms erected up to the 45° lines, all as shown by Fig. 22. The placing of the arch concrete completed the sewer barrel. The outside forms and bracing were removed about 24

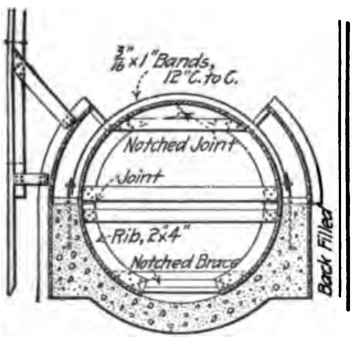


Fig. 22.—Concrete Sewer Construction.

hours after the completion of the arch, and backfilling the trench was begun immediately, but the inside forms were left in place for two weeks; they were then removed by the simple process of knocking out the notched braces. By building several lengths of invert first and following in succession by the side wall construction and then by the arch construction, the form erection and the concreting proceeded without interruption by each other. It was also found that, by making bends in the form of polygons with 10-ft. sides instead of in the form of curves, there was a material saving in expensive form work. To overcome the friction of the angles in such bends, an additional fall was provided at these places. All concrete was made in a Smith mixer mounted on trucks so that it could be moved along the bank of the trench and discharging into a trough leading to the work.

Labor Force and Cost.—With a gang of 12 men, from 24 to 36 ft. of sewer were built per 10-hour day, working only part of the

time on actual concreting. The disposition of the force mixing and laying concrete and the wages were as follows:

	Per day.
Six wheelers, at 18.5 cts. per hour	$11.10
One mixer, at 22.5 cts. per hour	2.25
One dumper, at 18.5 cts. per hour	1.85
Four placers, at 22.5 cts. per hour	9.00
Total	$24.20

There were 0.594 cu. yds. of concrete per lineal foot of sewer, and its cost is given as follows:

	Per cu. yd.
Gravel	$0.774
Sand	0.36
Cement	1.50
Steel reinforcement	0.84
Labor, mixing and placing concrete	1.094
Moving forms, templates, etc.	0.757
Forms, templates, etc.	0.589
Finishing, plastering, etc.	0.639
Tools and general expenses	0.841
Total	$7.395

The work was done under the direction of Mr. A. H. Hammond, M. Am. Soc. C. E., City Engineer, South Bend, Ind., to whom we are indebted for the information given.

Cost of a Large Reinforced Concrete Sewer at St. Louis, Mo.*— An unusual piece of sewer work is being carried out by the city of St. Louis. Harlem Creek, which drains a large area of the city and which has been made the outlet of district sewers until it has become a menace to health, is being replaced by a large reinforced concrete intercepting sewer. Ultimately the sewer will be several miles long, but at present only 2,200 lin. ft. of the lower end are under construction and about as much more is planned for early contract. The sewer under construction comprises 162 ft. of 29-ft. section, and 1,340 ft. of 27-ft. section; the 162 ft. of 29-ft. section have been completed and the following is an account of the methods of construction adopted by the contractors, the Hoffman-Hogan Construction Co., of St. Louis, Mo., with a statement of the cost of the work.

The interior dimensions of the sewer are 29 x 18.62 ft., giving an area of opening of 411 sq. ft. The grade of the sewer is 0.0025 per cent, which gives a velocity running full of 18.9 ft. per second and a capacity of 7,489 cu. ft. per second. The estimated run-off, calculated by McMath's formula, is 100 cu. ft. per second less. The area drained is about 6,000 acres and the maximum rainfall assumed is 2.75 ins. per hour.

The cross-section of the sewer is given by Fig. 23, which also shows the arrangement of the reinforcing bars. Johnson corrugated bars, old style, are used for reinforcement. The sections of the various reinforcing bars are: Longitudinal bars, 0.18 sq. in.: invert bars, 0.7 sq. in.; and arch bars, 0.7 sq. in. The spacing of

Engineering-Contracting, Feb. 20, 1907.

the bars and the arrangement of the splices are indicated on the drawings of Fig. 23. All splices have a lap of 36 ins. Some gravel concrete has been used in the invert, but most of the concrete has been crushed limestone and Mississippi River channel sand. The proportions were 1 : 3 : 6 in the invert and 1 : 2 : 5 in the arch. The arch was computed by Prof. Greene's method. The ultimate strength of concrete in compression was taken as 2,000 lbs. per sq.

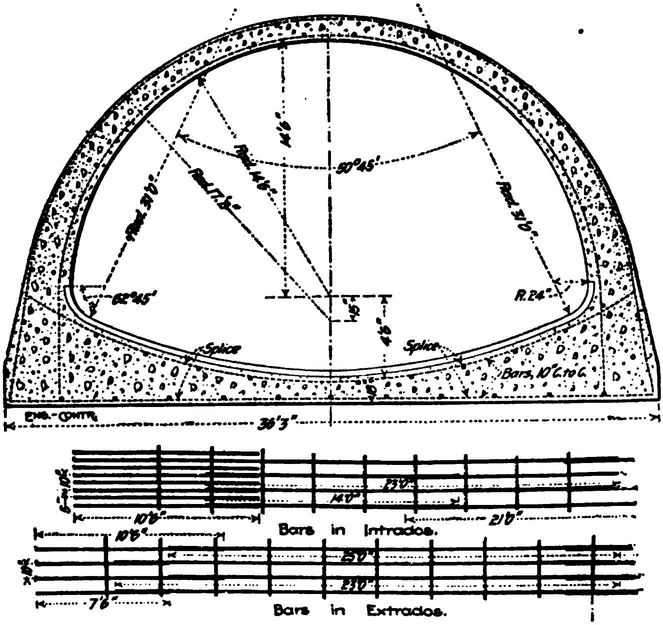


Fig. 23.—Reinforced Concrete Sewer.

in. and the working strength at 500 lbs. per sq. in. The elastic limit of the reinforcing bars was taken at 50,000 lbs.

The trenching was done by wheel scrapers to the amount of waste. Then a cableway was erected spanning the entire length of the section and the remainder of the material taken out. The last 4 or 5 ft. in depth were in limestone and the excavated rock was taken by cableway to dump carts which took it to the crusher and returned with crushed rock to be used for concrete. This rock foundation was taken advantage of to reduce the amount of invert concrete.

In constructing the sewer proper the invert was first concreted to template. The arch forms were then placed and the roof arch con-

creted. Both templates and arch forms were constructed of wood. The arch forms were moved ahead on iron rails and jacked into place. The ribs were 2 x 10-in. pieces and were spaced 4 ft. on centers; the lagging was 2-in. tongue and grooved stuff and was smeared with crude oil. The reinforcing bars were bent to proper radius by means of a wagon tire bender and were held in place by templates. The concrete was all mixed by two Chicago Improved Cube mixers operated by electric power.

The cost records of constructing the section of 29-ft. sewer so far built are not susceptible of complete analysis, but the following figures can be given. The prices of materials were as follows:

Cement, per barrel	$ 1.80
Sand, per cubic yard	0.75
Broken stone, per cubic yard	1.00
Reinforcing bars, per pound	0.02
Vitrified brick, per 1,000	12.00

The wages paid different classes of labor were:

	Per hour.
Firemen	$0.50
Laborers	0.175
Laborers	0.20
Laborers	0.25
Laborers	0.28
Laborers	0.3025
Bricklayers	0.66⅔
Helpers	0.25
Carpenters	0.55
Engineers	0.50
Timekeepers	0.25
Watchmen	0.175
Hostlers	0.175
Teams	0.60

Taking up the several items of work in order, the excavation amounted to 21,400 cu. yds., of which 1,400 cu. yds. were rock excavation. The cost of excavation was as follows:

	Total.	Per cu. yd.
Earth, excavation	$7,640	$0.38
Earth, bracing	2,000	0.10
Rock, excavation	1,400	1.00
Rock, dynamite, tools, etc.	560	0.40

The cost of crushing the excavated rock and returning it to the mixer was $1 per cu. yd.

The cost of the concrete work was as follows:

	Per cu. yd.
1.30 bbl. cement, at $1.80	$2.34
0.44 cu. yd. sand, at 75 cts.	0.33
1 cu. yd. broken stone, at $1	1.00
Total concrete materials	$3.67

There were 1,600 cu. yds. of concrete placed at a cost of for:

	Total.	Per cu. yd.
Mixing and placing	$1,180	$0.7375
Forms	2,000	1.25
Moving forms	400	0.25
Total for forms and labor	$3,580	$2.2375

For reinforcing the concrete 86,600 lbs. of steel, or about 55 lbs. per cu. yd., were used. The cost of placing and bending this steel was as follows:

	Total.	Per lb.
Placing	$172	0.20 ct.
Bending	52	0.06 ct.

We can now summarize the cost of the concrete work proper of this sewer as follows:

	Per cu. yd.
Cement, sand and stone	$3.67
55 lbs. steel, at 2 cts.	1.10
Forms, labor and materials	1.25
Mixing and placing concrete labor	0.74
Placing steel, at 0.20 ct. per lb.	0.11
Bending steel, at 0.06 ct. per lb.	0.03
Moving forms	0.25
Total labor and materials	$7.15

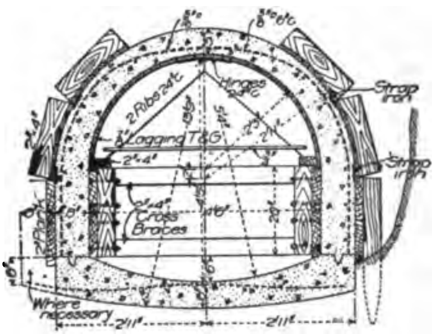


Fig. 24.—Reinforced Concrete Sewer.

To get the total cost of the sewer proper we must add the cost of the vitrified brick invert paving. There were 71 cu. yds. of this paving and its cost was as follows:

	Per cu. yd.
0.6 bbls. cement, at $1.80	$1.08
0.25 cu. yd. sand, at 75 cts.	0.19
450 bricks, at $12 per M.	5.40
Labor laying, 71 cu. yds., at $180.33	2.54
Total	$9.21

None of the preceding figures include the plant charges. The plant cost $12,000, and the cost of running it during the work described was $2,000. This plant will, of course, serve for the whole work under contract.

Cost of a Reinforced Concrete Sewer.—Mr. Wm. G. Taylor is authority for the following data.

The sewer had the section shown by Fig. 24; it was constructed

of 1:7½ concrete mixed to a mushy consistency using the forms shown by the illustration. The reinforcement was of twisted steel rods for parts of the work and of expanded metals for parts. When rod reinforcement was used it was bent on the bank and erected in cage form in the trench. The invert section was built as the first operation and the forms erected on it. The first cost of the forms shown was $1.80 per lin. ft. of sewer and the cost of maintenance was about 12 cts. per lin. ft., including depreciation and fixed charges. Petroline was used to grease the forms and was found superior to soft soap or to both light and dark mineral oils which were also tried. The concrete was deposited in level layers 6 ins. thick. The normal cost per lineal foot and per cubic yard of the sewer was as follows:

Materials:	Per lin. ft.	Per cu. yd.
Reinforcement (17½ lbs. per lin. ft.)	$0.43	$1.16
Cement (0.482 bbl. per lin. ft.), at $1.53	0.74	2.00
Sand (0.17 cu. yd. per lin. ft.), at $0.50	0.09	0.24
Stone (0.435 cu. yd. per lin. ft.), at $1.10 per ton	0.47	1.27
Total	$1.73	$4.67
Labor:		
Making and placing reinforcement	$0.14	$0.38
Operation of forms	0.16	0.43
Mixing concrete	0.30	0.81
Placing concrete	0.27	0.73
Screeding and finishing invert	0.08	0.22
Finishing interior surface	0.01	0.03
Sprinkling and wetting	0.02	0.06
Total	$0.98	$2.66
General charges:		
Interior forms, cons. and maint	$0.12	$0.32
Exterior forms, cons. and maint	0.05	0.14
Coating oil for forms	0.01	0.03
Cement, storage, handling and cartage	0.08	0.22
Total	$.26	$0.71
Grand total	$2.97	$8.04

In reference to these figures it should be noted that, as several contractors did the work, these are the composite costs. They include a foreman at 50 cts., a sub-foreman at 35 cts., common labor at 17½ cts., and teams at 50 cts. per hour. No administration expenses or contractor's profit are included.

Cost of Concrete Sewers, Richmond, Ind.—From a long and instructive article by Mr. Fred R. Charles, in *Engineering-Contracting*, Dec. 29, 1909, the following is an abstract:

Concrete Pipes.—Fifty-two-inch was the largest size used in concrete pipe. This was made according to the "Sheets" system, in which expanded metal is used for reinforcement; thickness of shell is 1 1/12 ins. per foot diameter; 24 ins. pipe made in 2½ ft., and larger sizes in 3-ft. lengths. Pipe is made in a mold consisting of an outer steel casing and an inner collapsible shell. The pipe rests on the end upon a pallet, and each end is formed by a shaping

ring, so that it is notched or rabbeted through half the thickness of the shell, on the outside for one-half the circumference, and on the inside for the other half circumference. The pipes are laid so as to form a groove at the joint, coming on the interior for the lower half and on the exterior of the upper half, whereby the mortar is always plastered downward in cementing the joint. For handling and placing in the trench a tripod or beam derrick is needed with a block and tackle or chain hoist, as the weight is considerable. Our average cost to lay these pipes, including plastering the joints, was for 42-in., $0.083; 30-in., $0.06; 24-in., $0.053 per lin. ft.

Monolithic Concrete.—Another sewer, 54 ins. in diameter, was built in horse-shoe shape, semi-circular arch, vertical sides and bottom slightly V shaped. It was in an open ditch or water course, so nearly all except the flow line was above ground, and outside forms were necessary, in the absence of the trench walls, to hold the concrete. First the bottom was laid as in sidewalks, and the vertical sides run up to the spring line with ordinary plank inner and outer forms, the expanded metal reinforcement having been bent and placed as before, with plenty of lap at the spring line. The arch was put on with a semi-circular "Blaw" form. On all these monolithic jobs the average labor hours per linear foot for the different operations of constructing the sewer, using "Blaw" forms and expanded metal reinforcement, is given in the following table. Knowing the wages paid labor per hour and the price of materials, this will be some guide to the cost in other places:

	Labor hours per lin. ft.
Placing flow line	0.48
Setting invert forms	0.50
Concreting invert	0.44
Setting arch forms	0.33
Concreting arch	0.25

For the lower half of the sewer the concrete should be very wet, so that it will flow freely around and under the forms; for the arch not so much water must be used; only enough to show quite perceptibly when concrete is tamped, as the concrete must have sufficient consistency to retain its position and not run off the arch; for the flow line the proper consistency is between the two. At first, house connections were provided for by building in ordinary vitrified slants or thimbles, but the flanges of these were frequently broken by falling rock and otherwise, so a change was made and an opening left in the concrete shell by means of a special form or core, devised by Mr. D. B. Davis, inspector on the work. This comprised two circular blocks of hard wood, nailed together; one 8 ins. in diameter and 2 ins. thick, the other 6 ins. in diameter and 3 ins. thick. Inserted in the concrete this left a good flange to receive the end of the 6-in. house connection pipe, and was extremely inexpensive, two of these blocks lasting for the whole season. The average cost of this work was as follows:

For 54-in. sewer, 5-in. shell, rib metal 10 ft.:

	Per lin. ft.
Cement, 0.347 bbl. at $1.25	$0.434
Gravel at $0.80	0.260
Rib metal	0.30
Forms (cost of)	0.125
Labor, 20 cts. per hour	0.230
Total cost, exclusive of machine and superintendence	$1.349

For 48-in. sewer, 5-in. shell, rib metal 9 ft.:

Cement, 0.29 bbl. at $1.25	$0.362
Gravel at $0.80	0.170
Rib metal	0.25
Forms	0.115
Labor, 20 cts. per hour	0.186
Total	$1.083

For 42-in. sewer, 4-in. shell, rib metal 8 ft.:

Cement, 0.20 bbl. at $1.25	$0.25
Gravel at $0.80	0.118
Rib metal	0.24
Forms	0.115
Labor at 20 cts. per hour	0.188
Total cost, exclusive of machine and superintendence	$0.911

Forms were made by the Adjustable Steel Centering Co., 6 ft. long, and 6 sections were used, which make 35 ft. of sewer, allowing for the necessary lap. These forms are especially well adapted to large sewer work, owing to the accessibility of all the parts, which renders them easy and inexpensive to handle. They are made of sheet steel with steel ribs on the inside at each end. These ribs are collapsed by especially made "collapsers"; forms then set in place.

Cost of Making Blocks for a Concrete Sewer.—At Coldwater, Mich., in 1901, there was built a concrete sewer with a monolithic invert and an arch of concrete blocks. Riggs & Sheridan, of Toledo, O., designed the sewer, and H. V. Gifford, of Bradner, O., was in charge of construction.

The sewer was circular, having an inner diameter of 42 ins., the thickness of the invert and the arch alike was 8 ins. The concrete was 1 of Portland cement to 6 of gravel. There were 11 concrete blocks in the ring of the arch, each block being 24 ins. long, 8 ins. thick, 8 ins. wide on the outside of the arch and 5¾ ins. wide on the inside of the arch. A block weighed 90 lbs. which was too heavy for rapid laying; blocks 18 ins. long would have been better. Some 8,500 blocks were made. Molds were of 2-in. lumber, lined with tin, for after a little use it was found the concrete would stick to the wood when the mold was removed. The four sides of the mold formed the extrados, the intrados, and the two ends of the block; the other two sides being left open. When put together the mold was laid upon a 1-in. board, 12 x 30 ins., reinforced by cleats across the bottom. The sides of the molds were held to-

gether with screws or wedge clamps. When the blocks had set, the sides of the molds were removed, and the blocks were left on the 12 x 30-in. boards for 3 days, then piled up, being watered several times each day for a week.

A gang of 14 men made the blocks; 2 screening gravel through 1-in. mesh screen; 4 mixing concrete; 4 molders; 3 shifting and watering blocks; and 1 foreman. With a little practice each molder could turn out 175 blocks a day; and since each block measured ¾ cu. ft., the output of the 14 men was 19½ cu. yds. a day. Mr. Gifford informs me that the wages were $1.50 a day for all the men, except the foreman. The daily wages of the 14 men were $22, so that the labor of making the blocks was $1.10 per cu. yd.

Each batch of concrete, containing ½ bbl. of Portland cement costing $1.35 per bbl., made 18 blocks. (1 bbl. per cu. yd.) Since the gravel cost nothing, except the labor of screening it, the total cost of each block was 11 to 12 cts., which includes 0.85 cent for use of molds and mold boards, which were an entire loss. At 12 cts. per block the cost was $4.32 per cu. yd.

The contract price was $3 per lin. ft. of this sewer, as against a bid of $3.40 per ft. for a brick sewer.

When the trenching had reached to the level of the top of the invert, two rows of stakes were driven in the bottom, stakes being 6 ft. apart in each row, and rows being a distance apart ¼-in. greater than the outer diameter of the sewer. Those stakes were driven to suen a grade that the top of a 2 x 4-in. cap or "runner" set edgewise on top of them was at the proper grade of the top of the invert. The excavation for the invert was then begun and finished to the proper curve by the aid of a templet drawn along the 2 x 4-in. runners. In gravel it was impossible to hold the true curve of the invert bottom. Concrete was then placed for the invert. To hold up the sides of the invert concrete, a board served as a support for the insides, but regular forms were more satisfactory in every respect except that they were in the way of the workmen. A form was tried, its length being 6 ft. It was built like the center for an arch, except that the sheeting was omitted on the lower part of the invert. It was suspended from cross-pieces resting on the "runners." After the concrete had been rounded in place, the form was removed and the invert trued up. This form worked well in soil that could be excavated a number of feet ahead, so that the forms could be drawn ahead instead of having to be lifted out; but in soil, where the concreting must immediately follow the excavation for the invert, the form is in the way. The invert was trued up by drawing along the runners a semicircular templet having a radius of 21½ ins. Then a ½-in. coat of 1:2 mortar was roughly troweled on the green concrete. Another templet having a 21-in. radius was then drawn along the runners to finish the invert.

When the plaster had hardened, two courses of concrete blocks were laid on each shoulder of the invert, using a 7:2:¼ mortar,

the ¼ part being lime paste. The lime made the mortar more plastic and easier to trowel. Then the form for the arch was placed, and as each 8-ft section of the arch was built, a grout of 1:1 mortar was poured over the top to fill the joints. Earth was thrown on each shoulder and tamped, and the center moved ahead.

Common laborers were used for all the invert work, except the plastering, which was done by masons who were paid 30 cts. per hr. Masons were also used to lay the concrete blocks in the arch. Mr. Gifford states that two masons would lay at the rate of 100 lin. ft. of arch per day, if enough invert were prepared in advance. As there were 11 blocks in the ring of the arch, this rate would be equivalent to 7½ cu. yds. of arch laid per mason per day.

Cost of Concrete Sewer Blocks.—The cost of molding several thousand concrete blocks to be used in sewer construction at Halifax, N. S., is given in the "Canadian Engineer," from which we rearrange and further analyze the figures as follows:

The work involved the mixing and molding of 356.35 cu. yds. of concrete in 1,341 batches of 7.17 cu. ft. each. The cost of the molded blocks was as follows:

	Total.	Per cu. ft.
5,050 hrs. labor, at 16 to 24 cts....	$ 838.76	$0.087
1,733 bushels cement, at 80 cts......	1,386.40	0.144
2,850 bushels sand, at 6 cts........	171.00	0.017
2,684 bushels gravel, at 6 cts.......	141.04	0.014
5,364 bushels stone, at 7 cts........	375.48	0.038
Paper	26.82	0.0028
Soap	17.85	0.0018
Coal	48.95	0.0050
Total	$3,006.30	$0.3096

The cost of the blocks complete was thus 31 cts. per cu. ft. or $8.37 per cu. yd. This cost includes cleaning molds, moving and storing blocks and all expenses incident to the cost of manufacture except the cost of the water used.

Cost of Concrete Block Manholes.—Mr. Hugh C. Baker, Jr., gives the following:

The cost of making concrete block manholes at Rye, N. Y., was as follows per manhole:

30 blocks for walls, 2.5 cu. yd. of 1:2:5 concrete....	$21.00
6 blocks for cover, ½ cu. yd. reinforced concrete...	4.27
I-beams for cover in place..........................	5.40
Supervision, freight and hauling, 5.6 tons concrete..	9.38
3 hrs. labor placing cover, at 15 cts..............	0.45
20 hrs. labor placing walls, at 15 cts..............	3.00
Total per manhole, exclusive of iron cover.....	$43.50

Each manhole was 5 ft. deep inside, 8-in. walls, 5 ft. in diameter. All concrete was hand-mixed, very wet, ¾-in. stone being used. A set of 30 wooden molds for the wall blocks was made. These molds cost from $3.50 to $12 each; some being made of hard wood lined with zinc. In making the blocks 4 men averaged 15 wall blocks a day of about 2½ cu. ft. each, which is equivalent to 0.84 cu. yd. per man per day. The concrete was allowed to set 3 to 12

hrs. before removing the molds; 24 to 36 hrs. before taking the blocks outside to dry, and 7 days before shipping the blocks. About 1,000 blocks were made and only 9 lost by breaking.

For comparison it is well to give the cost of brick manholes, as follows:

1,450 brick, at $8.25 per M	$11.96
Mason	6.00
46 hrs. labor, at 15 cts.	6.90
4 bbls. cement, at $1.25	5.00
Sand	.75
Supervision, etc.	2.50
Concrete top blocks (½ cu. yd.) and I-beams	11.40
Total	$44.51

This brick manhole had a flat concrete top.

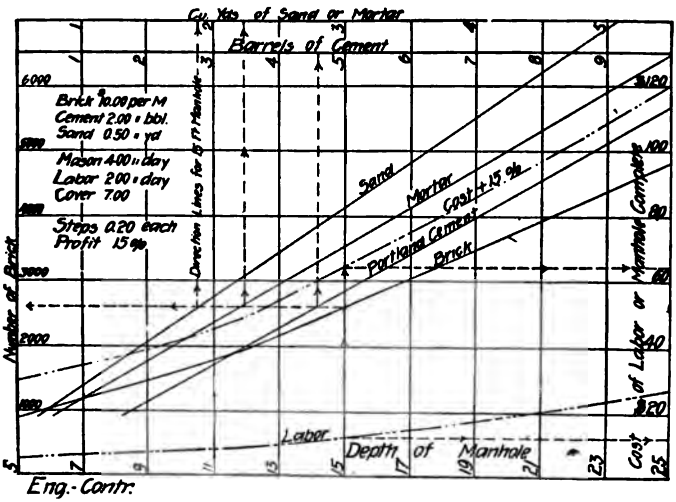


Fig. 25.—Diagram for Estimating Quantities in and Costs of Manholes.

Estimating the Cost of Manholes from a Diagram.—This diagram and the description of its use were given by Mr. John Wilson, in *Engineering-Contracting,* Dec. 8, 1908.

Herewith is given a diagram (Fig. 25) for estimating the quantities of materials in manholes; and, at given prices of materials and labor, the cost of the manhole can likewise be ascertained. The diagram shown is for a 4-ft. manhole.

Having the depth of the manhole given, the number of brick, the amount of sand, cement, mortar, the cost of labor, and total cost of manhole complete, plus 15 per cent profit, may be taken from the diagram.

Thus for a 15-ft. manhole, follow the vertical 15-ft. line to inter-

section with brick curve, thence horizontally to left read 2,600. From the intersections of the last horizontal line with the sand, mortar and cement curves, respectively, read vertically above 1.88 cu. yds. of sand, 2.22 cu. yds. of mortar and 4.6 barrels of cement. To ascertain the cost, follow the vertical 15-ft. line from bottom to intersection with the cost curves, and read horizontally to right, cost plus 15 per cent, $64, of which the cost of labor alone is $12.50, as shown by the labor curve.

The curves allow for a double layer of brick in the bottom and the outside of the manhole to be well plastered. It is an easy matter to draw similar curves to meet local conditions and thus secure a very ready method of making estimates.

A Device for Building Circular Manholes.*—We illustrate herewith a device (Fig. 26) for use in building circular manholes having a concrete bottom and brick walls. The device was designed

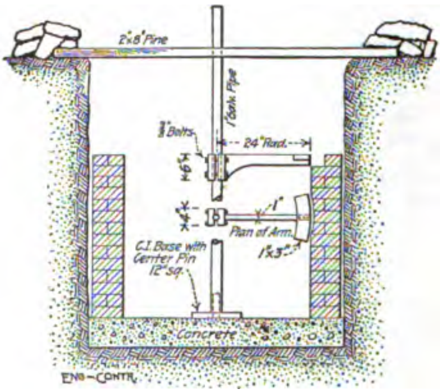


Fig. 26.—Device Used in Building a Manhole.

by Mr. Elmer E. Barnard, Assistant City Engineer of Lynchburg, Va., and has been in use in the sewer department of that city for about a year.

While the device was put in service with the primary object of getting a better class of work, yet both this has been obtained and the cost of the work has also been decreased quite a good deal.

Mr. Barnard informs us that, using the device, they have built two 10-ft. manholes in 2¼ days, two men at $1.40 per day each, and one man at $2.00 being employed.

Hence the labor cost of each manhole was:

2¼ days, at $1.40	$3.15
1⅛ day, at $2.00	2.25
Total	$5.40

*Engineering-Contracting, Sept. 19, 1906.

It has been found that on a system where a large number of manholes are to be installed, they can be built in much less time than the figures given above, owing to the fact that the concrete bottoms can be put in before the bricklayers have gotten up to the work.

Cost of a Concrete Manhole.—The following figures of the cost of constructing a concrete manhole are rearranged from the "Canadian Engineer." The construction of the manhole is clearly shown by the accompanying sketch (Fig. 27). About the only point that need be noted is that the form lumber was so cut up that it could not be used again and its total cost is therefore charged against the

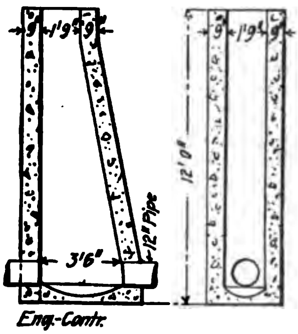


Fig. 27.—Concrete Manhole.

work. The costs were as follows, there being 4.08 cu. yds. of concrete in the manhole:

	Total.	Per cu. yd.
Materials:		
300 ft. B. M. lumber, at $30	$ 9.00	$ 2.21
5 bbls. cement, at $2.25	11.00	2.69
4 cu. yds. sand and gravel, at $1	4.00	0.98
Total materials	$24.00	$ 5.88
Labor:		
Forms, 70 hrs., at 32½ cts.	$22.75	$ 5.57
Mixing and placing concrete: 13 hrs., at 22½ cts.	$ 2.92	$ 0.71
Total labor	$25.67	$ 6.28
Total labor and materials	$49.67	$12.16

Cost of Brick Manholes.—The walls of brick manholes are generally 8 ins. thick up to 12 ft. in depth, and 12 ins. thick below. The cross-section of manholes is usually elliptical, 3 ft. x 4½ ft., up to the neck of the manhole which is circular and narrows down to about 24 ins. in diameter. The cast-iron ring and cast-iron cover weigh from 375 lbs. to 650 lbs., the lighter weight being used in village streets. A common weight for use in cities is 475 lbs. These "manhole heads" are carried in stock by manufacturers of sewer

pipe, and are listed in their catalogues. The following is the actual cost of a manhole built by day labor for a Western city:

2,000 brick, at $6	$12.00
475-lb. ring and cover, at 2 cts.	9.50
2⅔ bbls. Louisville cement, at 75 cts.	2.00
1 cu. yd. sand	1.50
24 hrs. bricklayer, at 55 cts.	13.20
24 hrs. helper, at 18¾ cts.	4.50
Total	$42.70

It will be noted that the mason averaged less than 700 bricks per 8-hr. day, which indicates that he realized that he was working for a city and not for an individual. However, small jobs like manhole work are apt not to be handled with rapidity. Consult, for comparison, other data. See "Manhole" and "Vault" in the index.

Cost of a Brick Manhole, Flush Tank and Laying Pipe Sewer.*— The following data relate to the construction of a brick manhole, a brick flush tank, and the laying of a section of sanitary sewer at Columbus, Mass. The work was constructed by day labor.

Brick Manhole.—The manhole was 4 ft. in diameter and 6½ ft. deep; it was of the "churn pattern." Its cost was as follows:

1,000 hard brick, at $6.50	$ 6.50
7 sacks Portland cement, at 50c	3.50
1 cu. yd. sand, delivered	0.85
Ring and cover, 395 lbs., at $2.40 per 100 lbs.	9.48
3 step irons	0.30
Hauling iron	0.20
Digging hole—in brick clay	2.25
Filling	0.75
Mason, 8 hours, at 55 cts.	4.40
Helper, 8 hours, at 12½ cts.	1.00
Total actual cost	$29.23
Engineers' estimate of cost	$30.00

Brick Flush Tank.—The flush tank was 4 ft. in diameter by 5 ft. deep. Its cost was as follows:

650 brick, at $6.50	$ 4.22
9 sacks Portland cement, at 50 cts.	4.50
1 load sand	.50
1 load gravel	.60
Ring and cover, 395 lbs., at $2.40 per 100 lbs.	9.48
5-in. automatic syphon	22.10
Freight	.65
Drayage	.45
Drain pipe	.50
Digging and filling (sand)	1.50
Mason, 9 hours, at 55 cts.	4.95
Helper, 9 hours, at 12½ cts.	1.13
Total actual cost	$50.58
Engineer's estimate of cost	60.00

Laying Sewer.—The sewer was 1,613 ft. long, of 8-in. terra cotta pipe. The sewer pipe was furnished by the city, delivered on the job, so that the following is the cost of laying only.

Four manholes and one flush tank were also constructed, but these were paid for separately and their cost is not included in the

*Engineering-Contracting, June 9, 1909.

figures below. The average depth of the trench was 6½ ft. The work was completed in 14 days of 10 hours each. The cost was as follows:

	Total.	Per lin ft.
Labor, 1,639½ hours, opening trench, laying and backfilling with shovels, at 10 cts. per hour	$163.95	$0.1016
Wiping joints (acting foreman), 143 hours, at 15 cts.	21.45	.0133
Superintendence, 14 days, at $5	70.00	.0434
Cement, 12 sacks, at 50 cts.	6.00	.0037
Sand, 3 loads, at 50 cts.	1.50	.0010
Total	$262.90	$0.163

We are indebted to Charles Lyon Wood, C. E., Columbus, Mass., for the above information.

Cost of Making Cement Pipe.—Mr. Arthur S. Bent gives the following data: In 1892 four miles of 28-in. cement pipe were laid for an irrigation system in Riverside county, California. The mortar was mixed by hand in boxes holding ⅓ cu. yd., and was hoed over 3 times dry and 3 times wet. It was then tamped (17-lb. tampers) by hand into sheet iron molds.

The pipe was 28 ins. in diameter, 2½ ins. thick and in 2-ft. lengths. The mixture used was 1 part Portland cement and 3½ parts pit gravel and sand. During the best week's work, a gang of 25 men made 1 mile of pipe, or 35 ft. per man per day, or 1¾ cu. yds. of concrete per man per day. But the average week's work was ½ mile of pipe made by a gang of 25 men, or 17 lin. ft., or 0.9 cu. yd. per man per day. The laborers received $2 and upward per day.

This pipe line, after seven years of use, showed no appreciable loss of water in its 4 miles of length.

The Miracle Pressed Stone Co., of Minneapolis, Minn., manufacture molds for making cement tile and cement sewer pipe with bell ends. Their catalogue contains the data given in the following table:

COST OF CEMENT PIPE, IN 2-FT. LENGTHS.

(Mortar, 1:3 mixture; sand, 75 cts. per cu. yd.; cement, $2 per bbl.; labor, $2 per day.)

Kind of pipe.	Thickness.	Cu. ft. of sand.	Cost of sand.	Cost of cement.	Cost of labor.	Tot. cost 2-ft. pipe.	Total cost per ft.
		—Pipe, 2 ft. long.—					
24" Bell-End...	2"	2.75	$0.075	$0.460	$0.15	$0.685	$0.34
24" Straight....	2"	2.25	.063	.370	.12	.553	.28
20" Bell-End...	1¾"	1.95	.056	.325	.13	.511	.26
20" Straight....	1¾"	1.67	.045	.266	.09	.401	.20
18" Bell-End...	1¾"	1.84	.055	.230	.13	.445	.22
18" Straight....	1¾"	1.50	.045	.190	.10	.335	.17
15" Bell-End...	1⅝"	1.40	.039	.235	.11	.384	.19
15" Straight....	1⅝"	1.17	.033	.195	.08	.308	.15
12" Bell-End...	1½"	1.10	.030	.180	.10	.310	.16
12" Straight....	1½"	.88	.026	.145	.07	.240	.12
10" Bell-End...	1⅜"	.83	.025	.105	.10	.230	.12
10" Straight....	1⅜"	.68	.020	.850	.07	.175	.09

Cost of Cement Pipe Sewer and Manholes at Brooklyn, N. Y.— The following records of the methods and cost of constructing a 24-in. egg-shaped cement pipe sewer in Butler street, Brooklyn, N. Y., were furnished by Mr. J. J. B. LaMarsh and published in *Engineering-Contracting*, Oct. 3, 1906. A plan and profile of the sewer are shown in Fig. 28., which gives all lengths. The work included trenching, pipe-laying and backfilling, manhole construction and catch basin construction.

The trench had an average depth of 12 ft. and was opened 3 ft. wide throughout. For the first 2 ft. the soil was loam and for the remainder of the depth it was gravel and sand. Picks were used. The timbering consisted of 1⅛ x 12-in. vertical sheeting held by 2 x 10-in x 16-ft. rangers and 4-in. diameter bars 3 ft. long.

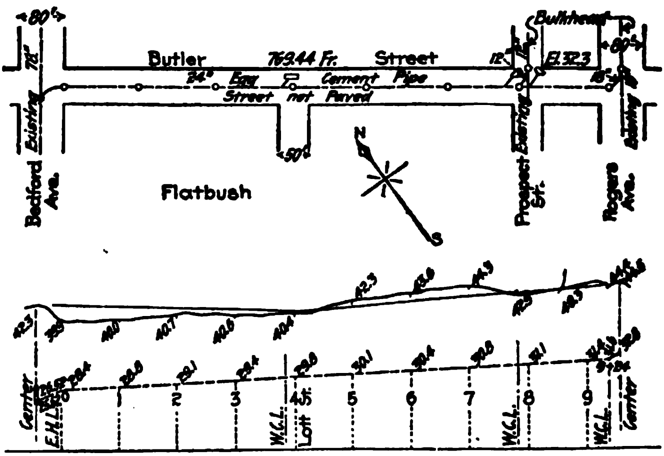


Fig. 28.—Plan and Profile of Sewer.

The sheeting was easily placed, as the bank stood until dried by the sun. On the 18-in. pipe curve into Rogers avenue the sheeting was left in place, but all the other timbering was removed.

The pipe was laid on a foundation plank 1¼ x 12 ins. It was cement pipe manufactured by the Wilson & Baillie Mfg. Co., and was of the general form shown by Fig. 29. It came in 3-ft. lengths, weighing for the 24-in. size 500 lbs. each. It was laid with a three-leg derrick, using a goose-neck to lower. Four men handled the pipe to the derrick and lowered it and two men in the bottom of the trench placed it. There was no separate pipe gang, the work being done by men taken from the trenching gang and in stretches of from 3 to 20 lengths, as the progress of work necessitated. In all 933 ft. of 24-in. pipe were actually laid, although the contractor got paid for 964 ft.; the difference of 31 ft. was taken up in the

3 x 5-ft. manholes. Besides the 24-in. pipe main, there were 36 ft. of 18-in. pipe, 33 ft. of 12-in. pipe, 10 manholes and 3 sewer basins.

Turning now to the cost of this work we have the following figures:

Amounts and Cost of Materials Used.

18,500	brick, at $8.75	$ 161.875
27	barrels of cement, at $1.35	36.450
10	manhole heads and covers, at $11.00	110.000
5,500	ft. B. M. lumber, at $18.50	46.750
3	sets granite stones for basins, at $35	105.000
3	sets blue stones for basins, at $5	15.000
3	pans and hoods, at $9.50	28.500
933	ft. 24-in pipe, at $1.43	1,334.190
36	ft. 18-in. pipe, at $0.85	30.600
96	ft. 12-in. pipe, at $0.40	38.400
	Total cost of materials	$1,906.765

Fig. 29.—Cement Pipe for Sewer.

Owing to the method of doing the work the labor costs can be only partially classified. The trenching, sheeting, pipe-laying and backfilling were all done by the same gang, the men changing from one item to another, as occasion demanded. As a rule, the whole gang was worked on backfilling from 4:30 to 6 p. m. each day; there was no ramming.

Of the 5,500 ft. B. M. of lumber, the contractor got paid for

3,250 ft. B. M., leaving 2,250 ft. B. M. lost from use. In this connection it should be noted that about 40 loads of sand from the excavation were sold by the contractor at 25 cts. a load, or a total of $10.

The team work was mostly hauling brick and lumber; the outfit was owned by the contractor and with driver was estimated to cost $3.50 per day. The labor thus is itemized as follows:

Trenching, Pipe-laying, Timbering and Backfilling.

	Total.	Per lin. ft. Cts.
One foreman, 34 days, at $3.50	$119.000	11.90
One boy, 317 days, at 75 cts.	23.775	2.37
One bracer, 34 days, at $2.40	81.600	8.16
Labor, A, 172.5 days, at $1.70	293.250	29.32
Labor, B, 192.9 days, at $1.60	308.640	30.86
Team and driver, 12 days, at $3.50	42.000	4.20
Total	$868.265	86.82

These figures per foot are based on 1,002 ft. of sewer, namely, 933 ft. 24-in., 36 ft. 18-in., and 33 ft. 12-in. sewer. They include labor, excavating and backfilling, manholes and basins, but not the mason's labor. With a trench 3 ft. wide and 12 ft. deep, there were 1.33 cu. yds. of trench excavation per lin. ft.; hence the excavation cost 65 cts. per cu. yd.

The labor for ten manholes and three basins was as follows:

Mason, 12.4 days, at $7	$ 86.80
Mason's helper, 12.4 days, at $2.10	26.04
Total	$112.84

The actual cost of one sewer basin was as follows:

Sewer Basin.

Materials:	
1 set granite	$35.00
1 set bluestone	5.00
1 hood and pans	9.50
2,100 brick, at $8.50	17.85
3 barrels cement, at $1.35	4.05
21 ft. 12-in. pipe, at 40 cts.	8.40
Total materials	$79.80
Labor:	
5 men, 1 day, excavating and backfilling, at $1.70	$ 8.50
1 mason, 1 day, at $7	7.00
1 helper, 1 day, at $2.10	2.10
Total labor	$17.60
Grand total	$97.40

The manholes were 3 x 4 ft. of brick masonry. The actual cost of one manhole was as follows:

Manhole.

1 head and cover	$11.00
1,600 brick, at $8.50	13.60
1½ barrels cement, at $1.35	2.03
1 day mason, at $7	7.00
1 day helper, at $2.10	2.10
Total	$35.73

From the preceding figures the total cost of the work may be summarized as follows:

Materials	$1,906.765
Labor	981.105
Total	$2,887.870
Deduct sand	10.000
Total	$2,877.870

In this total there is no wear on tools, interest on money invested, oil for 10 lanterns, or payment on bond included. There was no insurance on men.

Cost of Constructing Cement Pipe in Place.*—The method of making cement pipe in place, which will be briefly described in this article, is an invention of Mr. Ernest L. Ransome.

A short stretch of 8-in. pipe was built at the rate of 1 lin. ft. per minute by six men and a foreman. The men were working with great energy, and the records show that they actually averaged about half this rate, their average being 300 lin. ft. per 10-hr. day.

As shown in Fig. 30, three men work in the trench, one of the men packing the cement mortar in the mold, one continuously pulling the mold ahead by means of the lever and the third filling around the green pipe with earth. The other three men mix mortar and deliver it into the trench.

Before giving the cost of this pipe, a word as to the method of construction:

The mold, Fig. 31, is made of sheet steel with an inner core 10 ft. long. The front end of this core is surrounded by a short steel shell that serves as the outer form for the cement pipe. The mortar for the pipe is packed in between the inner core and this outer shell by a man who uses a small wooden rammer for the purpose as shown in Fig. 30. The man standing in the foreground keeps moving the mold forward slowly by means of the lever grasped in the right hand. This lever is provided with a dog that works in a ratchet and thus rotates a small drum upon which a wire rope is wound. The wire rope is anchored into a deadman in the trench ahead. As the mold is thus moved forward it leaves behind it the cement pipe which is still green. The cement mortar, however, is mixed with a small amount of water so that it possesses sufficient cohesion to hold together when unsupported by the core. To protect the pipe until it hardens, it has been found advisable to pack a little earth around its sides and over the top; this is done by the third man in the trench, and he does this backfilling upon the part of the pipe that is still supported by the core.

In verbally describing this feature of the construction two questions have invariably been asked:

1. Doesn't the pipe cave in occasionally, especially when it is of large diameter?
2. How are branches put in?

**Engineering-Contracting*, March, 1906.

Fig. 30.—Ransome Cement Pipe Mold in Trench.

Answering the first question, Mr. Ransome says that caving does not occur except when some heavy object falls upon the pipe before the cement has hardened. The pipe does not break down of its own weight even when made three feet in diameter.

To put in a branch a hole is cut in the side of the "green" pipe before the core has been pulled ahead. A branch of the proper pattern is shoved up tightly against the pipe and the collar of the branch is plastered with cement mortar, producing a strong water-tight joint.

The following was the itemized cost of an 8-in. cement pipe, built as before described, at Despatch, N. Y.:

6 men, at $1.70 per day, 10 hours	$10.20
1 foreman	2.00
3 bbls. cement, at $1.25	3.75
3.3 cu. yds. sand, at 85 cts.	2.80
Water	.15
Total for 300 lin. ft.	$19.90

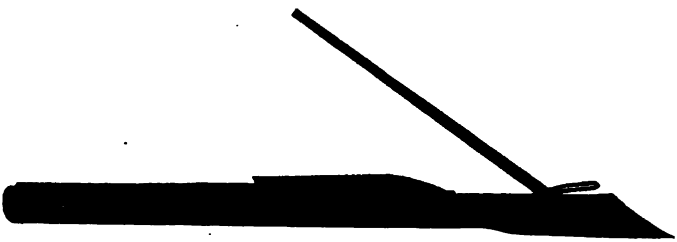


Fig. 31.—Ransome Cement Pipe Mold.

This is equivalent to 6.63 cts. per lin. ft. of pipe. It should be added that the shell of this particular 8-in. cement pipe was made unusually heavy, being 1½ ins. thick.

On another stretch of 12-in. pipe the cost was as follows:

	Per day.
7 men, at $1.70	$11.90
1 foreman	2.20
13 bbls. cement, at $1.33	17.30
12 cu. yds. fine gravel, at 88 cts.	9.60
Total for 400 ft. of pipe	$41.00

This is equivalent to 10¼ cts. per ft. In none of these cases is the cost of digging the trench included in the labor item, for that cost is common to all kinds of pipe sewers. However, due to the fact that there are no bells on the cement pipe and no joints to be made, the trench can be dug about 6 ins. narrower than where vitrified pipe is used, thus effecting considerable saving in the cost of excavation.

It was noted that in building the 8-in. pipe the men in the trench were capable of putting in pipes at the rate of 1 lin. ft. per minute, which was just about twice what they averaged for the whole job.

The speed depends very largely upon the man who is packing the mortar into the mold, and as this is hard work, it would be advisable to let him change places frequently with the man who works the lever that pulls the mold ahead. By having two strong and willing men in these positions, it is believed that 500 lin. ft. of 8-in. pipe could be built in 10 hours, day in and day out.

The molds for making this pipe are made by the Ransome International Conduit Co., 11 Broadway, New York City.

Cost of Cleaning a Large Brick Sewer.—Mr. Frederick L. Ford gives the following, relating to work done in Hartford, Conn., in 1905.

The Franklin avenue sewer cleaned consists of 9,269 lin. ft. of circular brick sewer, 5,128 ft. of which is 6 ft. inside diameter; 2,225 ft. 4 ft., and 1,916 ft. 3 ft. inside diameter. This sewer was built in 1872-73, at a cost of about $150,000, and drains a district containing about 1,167 acres. It has never been thoroughly cleaned since it was built. The sewers which discharge into this trunk sewer vary from 8 ins. to 3 ft. in diameter, and have grades ranging from 0.5 to 6.0 ft. per hundred. The 6-ft. Franklin avenue sewer has a grade of 2 ft. per 1,000, and the 4 and 3-ft. sections a grade of 3 ft. per 1,000.

The first work done was a thorough inspection of the sewer to determine the location and amount of the deposits. In the 6-ft. sewer this was an easy task with lanterns, and the material was found only in patches on the bottom, averaging from 6 ins. to a foot deep and from 50 to 150 ft. in length, located usually just below where some large tributary sewer entered the Franklin avenue sewer.

It was impossible to make a thorough advance inspection of either the 4 or 3-ft. sections of the sewer, as the manholes were, as originally built, sometimes 1,000 ft. apart, and the ventilation so bad that we found it suffocating and too dangerous to enter either for any great distance from any manhole.

The deposits in the 3-ft. sewer were found, upon opening the sewer, to average about 1 ft. in depth and the ordinary sewage, about 6 to 8 ins., was running on top of it, so there was little available working space left.

The cleaning was done by a contractor on a percentage basis (15%). The laborers received $2 a day, and their foreman received $15 per week.

Before commencing the cleaning, manholes were built where necessary, so that they are now not more than 300 ft. apart, and often less on the smaller sizes.

In cleaning, the force was organized in small gangs, which could work to advantage; two starting at a manhole and working in opposite directions until they met the men coming in the opposite direction.

In the 6 and 4-ft. sections, wheelbarrows were used to convey the material to the nearest manhole, where it was hauled up and re-

moved in carts, each holding 1 cu. yd. In the 3-ft. sewer the men used pails to remove the deposit.

The result of the work was as follows:

Diam. sewer.	Length.	Loads.	Cost.
6-ft.	5,128 ft.	107	$ 387.55
4 ft.	2,225 ft.	61	243.80
3-ft.	1,916 ft.	107	466.38
Total	9,269 ft.	275	$1,097.73

The average cost per load (cubic yard) on 9,269 ft. of sewer was $3.99, and the average cost per lineal foot was $0.118.

Size of sewer, ft..........	6	4	3
Cost per load..............	$3.62	$3.99	$4.36
Cost per foot..............	0.075	0.109	0.243

The 6-ft. sewer was cleaned in 7 days. The total time on this work, including foreman and team, was 1,592 hours. This is equivalent to 22.7 men working 10 hours a day for 7 days.

The 4-ft. sewer was cleaned in 4 days. The total time was 1,000 hours, equal to 25 men employed 10 hours a day for 4 days.

The 3-ft. sewer was cleaned in 13 days. The time occupied was 2,019 hours, or an average of 15.3 men, working 10 hours a day for 13 days.

The average distance cleaned by each man per day on the 6-ft. sewer was 32 ft.; on the 4-ft. sewer, 33 ft., and on the 3-ft. sewer, 9 ft.

The total cost of the work, including manholes built, was $1,395.47, of which 15% was paid to Mr. Charles H. Slocomb, who furnished the labor and materials and superintended the work.

Cost of Cleaning Sewers and Catchbasins.—The following tabulation shows the amount expended per mile per year for the past 21 years by the Bureau of Sewers of Chicago, Ill., in cleaning sewers and catch basins:

	Miles of sewer to maintain.	Cost of cleaning.	Cost per mile per year.
1887	474	$ 50,264.65	$106.04
1888	492	52,423.41	106.55
1889	712	61,503.01	86.38
1890	785	107,878.34	137.42
1891	888	123,620.44	139.21
1892	992	142,720.52	143.87
1893	1,145	132,633.51	115.84
1894	1,211	154,225.45	127.35
1895	1,248	134,424.44	107.71
1896	1,306	96,901.65	74.20
1897	1,345	91,414.89	67.96
1898	1,388	92,961.88	66.98
1899	1,424	72,439.07	50.92
1900	1,453	80,985.64	55.73
1901	1,475	94,369.87	63.98
1902	1,501	99,372.58	66.20
1903	1,529	118,303.41	77.37
1904	1,583	124,260.26	79.50
1905	1,615	127,003.97	78.64
1906	1,633	150,942.10	92.43
1907	1,673	204,329.37	122.13

The work is done by regular employes of the Bureau of Sewers, common laborers during 1907 receiving $2.50 and up per 8-hr. day.

Cost of Cleaning Sewers and Catchbasins.—The following table shows the cost of sewers cleaned in the city of Chicago during the year 1907:

Method.	Feet cleaned.	Total.	Per ft., cts.
Flushing	2,485,900	$29,060	1.17
Iron scraper	488,700	32,161	6.58
Wood scraper	6,200	204	3.29

A total of 24,974 catchbasins were cleaned at a cost of $96,522, the average cost per basin being $3.86. The work is done by day labor by the Bureau of Sewers, common labor being paid $2.50 per day of 8 hours.

Cost of Sewage Purification at Providence, R. I.—The cost of treatment per million gallons of sewage during 1906 at Providence, R. I., was as follows: Chemical precipitation, $3.50; sludge disposal, $3.10. The population served by sewers in 1906 was about 182,000, according to the annual report of Otis F. Clapp, City Engineer. The sewerage system included 205.89 miles of combined sewers and 9.94 miles of storm sewers. The sewage was composed of manufacturing, wool washings, jewelers' dyeing and bleaching wastes, with domestic sewage, and the strength of average sewage (parts per 100,000) was: Albuminoid ammonia, total 0.729; soluble, 0.370; suspended, 0.359; chlorine, 45.58. Other data from Mr. Clapp's report were as follows: Daily flow of sewage in million gallons: Maximum, Dec. 31, 43.5; minimum, Aug. 19, 10.3; average for the year, 20.36. Average daily flow of sewage treated: 19,550,000 gals. Pounds of lime used per million gallons of sewage (treated): 637.75. Other chemical used: Copperas, 72.1 lbs. per million gallons. Cubic contents of settling basin up to water surface, when in use, in million gallons: 11.13. Per cent organic matter removed from sewage in terms of albuminoid ammonia. Total, 43.35; suspended, 85.07. Disposition of effluent: Discharged into Providence River off the end of Field's Point under 36 ft. of water. Volume of sludge produced in gallons per million gallons of sewage treated: 4,444.4. Per cent of solids in wet sludge: 7.43. Method of sludge disposal: Pressed and cake hauled by steam train to dump. Sludge pressing: Average number of gallons pumped per day, 86,893. Per cent of solids in wet sludge: 7.43. Pounds of lime added per thousand gallons of sludge: 23.07.

Sludge Disposal.—Description of machinery used: Sludge pumped by Shone ejectors (two, 500 gals.) to storage reservoirs; thence by gravity to forcing receivers (four, 8 ft. dia. x 12 ft. long); thence forced under 60 to 80 lbs. pressure per square inch up into the presses. The ejectors and forcing receivers are run by air pressure generated by one 150 and one 50-hp. air compressors actuated by electric motors; 18 filter presses are used, each with from 43 to 54 plates, with 6-in. center holes, forming cakes 36 ins. square and from 1¼ in. to ¾ in. thick, between filter cloths which sur-

round the plates. Hours of operation of presses daily: 6.83. For light, heat and power, $7.69 per day. Tons of sludge cake produced daily: 97.16. Per cent of solids in pressed cake: 27.7 Tons of solids in sludge cake produced daily: 26.97. Cost of operation per ton of solids: $2.24. The quantities per day in above table are calculated on basis of 365 days' work.

Cost of Sewage Disposal, 6 Cities.—In *Engineering-Contracting*, Oct. 6, 1907, appeared a five-page article compiled from a report prepared by Mr. A. C. Gregory. It contains many valuable data relating to six cities, of which the following is a very brief abstract.

Chemical Precipitation, Providence, R. I.—Providence has the distinction of being the one large city in this country which treats all (except in time of heavy storm) of its sewage by chemical precipitation, the object, of course, being clarification. This is all that is considered necessary, inasmuch as the clarified effluent is discharged into the Providence River and speedily carried into Long Island Sound, where the dilution is amply sufficient to take care of what organic matter remains in the effluent.

The disposal works consist of a pumping plant, chemical house, precipitation tanks and sludge compressing house with sludge well and tanks and a chemical laboratory.

A pound of lime used as a precipitant produces 10 lbs. of sludge (Dunbar, 1908) and that the amount of sludge amounts to about three times that produced by sedimentation or septic tank action.

Population in 1907, 208,000.

Population served by sewers, about 185,000.

Length of sewerage system: Combined, 209.8 miles; storm, 10.11 miles.

Character of sewage: Manufacturing, wool washings, jewelers, dyeing and bleaching waste, with domestic sewage.

Daily flow of sewage, in gallons: Maximum, 40,462,000; minimum, 9,424,000; average for year, 19,329,000.

Pounds of lime used per million gallons of sewage treated, 653.54.

Other chemicals used: Copperas, 83.05 pounds per million gallons.

Volume of sludge produced in gallons per million gallons of sewage treated, 4,504.

Per cent of solids in wet sludge, 7.85.

Average number of gallons of sludge pumped per day, 83,660.

Hours of operation of sludge presses per day, 671.

Tons of sludge cake produced daily, 96.84.

Tons of solids in sludge cake produced daily, 28.2.

Cost of treatment per million gallons of sewage: Chemical precipitation, $3.54; sludge disposal, $3.07; total, $6.61 per million gallons.

Annual cost of maintenance about 22.4 cts. per capita.

Per cent of organic matter removed from sewage in terms of albuminoid ammonia, 44.74, and of suspended matter, 83.92.

In the analysis of sewage the amount of albuminoid ammonia found is a valuable index of the amount of organic matter present.

Chemical Precipitation, Worcester, Mass.—The Worcester disposal plant consists of a chemical house for storing and mixing the lime precipitant, and also containing sludge presses, a chemical laboratory, 16 precipitation tanks and 61 acres of filter beds.

The sludge is finally deposited at a distance of about a mile from the works. During the year ending with Nov. 30, 1908, 15,930,000 gals. of semi-liquid sludge were pumped from the precipitation tanks. After as much as possible of the liquid had been drawn off the remaining 12,074,000 gals. were pressed into sludge cake, amounting to 12,987 tons. Of this about 10,000 cu. yds. were taken as fertilizer by farmers.

The above figures, together with those that follow, are taken from or based upon the report of the city engineer for 1908:

Average daily quantity of sewage treated (precipitation), 11,-240,000 gals.

Length of time sewage remains in tanks, 4 to 8 hours.

Volume of sludge per million gallons of sewage, 3,872 gals.

Cost of tanks, $265,628.75.

Cost of maintenance for year, including disposal of sludge, $35,671.15.

Kind and quantity of chemicals used per 1,000,000 gals., 871 lbs. of lime.

Cost of chemical precipitation per 1,000,000 gals., $4.82; sludge pressing, $3.85; total, $8.67.

Annual cost of maintenance per capita, about 26.5 cts.

In terms of albuminoid ammonia chemical precipitation removes 37.3% of the total organic matter and 75.3% of the suspended organic matter.

Intermittent Sand Filtration, Worcester.—There are in use about 61 acres of sand filters, divided generally in units of one acre and having a depth of from 4 to 6 ft. A large part of this area is a natural sand bed, by reason of which fact a considerable saving was effected. At the bottom of the beds are laid parallel lines of drain pipes at intervals of about 50 ft. These collect the effluent and carry it to an intercepting pipe, whereby it is conveyed to the main effluent channel and finally reaches the Blackstone River.

Date of construction of works, 1899-1908.

Cost of beds, $263,340.93.

Total filtering area, 61 acres.

Average area of beds, 0.98 acre.

Average daily quantity of sewage treated, 4,022,000 gals.

Average daily quantity treated per acre, 79,000 gals.

Annual cost of maintenance per capita, about 10½ cts.

Sewage flows on one bed, two to six hours.

Beds used, one to four times weekly.

Cubic yards material removed from surface of beds, 23,804.

Cost of removing same, $8,500.

Total cost of maintenance for year, $13,555.37.

Cost of maintenance per million gallons of sewage treated, $9.21.

The net cost of maintenance per capita for both sand filtration and chemical precipitation is slightly less than 37 cts.

Intermittent Sand Filtration, Brockton, Mass.—There are 37 filter beds of an acre each. The use of water meters has brought water consumption down to 35 gals. per capita.

The sewage runs by gravity to a sump (pit) passing through screens before entering the sump, and from which it is pumped to the disposal beds about three and one-quarter miles away. About 110 lbs. of refuse per 1,000,000 gals. is screened out before the pumping. No pumping is done at night, the sewage being allowed to collect during that time, and is pumped away on the following day. A considerable amount of sediment is deposited in the sump. This is stirred up, pumped to the disposal plant, and applied to beds, of which there are five, especially used for that purpose, an average of about 136,000 gals. of sludge sewage being thus treated each day. The average amount of sewage treated per day at Brockton amounts to about 1,208,000 gals. The minimum seems to be about 1,079,000 gals., and the maximum about 1,433,000 gals. This would indicate a rate of about 45,000 gals. per acre per day.

The population of Brockton is estimated at 55,000.

The above figures are for 1908. In reaching the bed from the pumping station the sewage travels 3.3 miles and is raised 42 ft.

The Brockton plant has been placed in a spot naturally lending itself to economical construction. For the most part the preparation of the beds consisted in removing the upper soil so as to leave exposed the sand and gravel underneath. Under drains were put in only where the sand at a depth of 5 or 6 ft. was too fine to allow the sewage to percolate freely through it. Where such a condition existed drains with open joints were placed about 40 ft. apart. Banks were also raised and the necessary dosing arrangements made.

The disposal plant, up to Jan. 1, 1909, has cost $337,488.64.

Seven new beds, constructed in 1907 and 1908, were completed at a cost of $23,239.06, or at about $3,320 per bed.

The expense for maintenance of the beds during 1908 amounted to $6,169.04, or about $12.53 per million gallons filtered, or 11.2 cts. per capita.

Intermittent Sand Fitration, Saratoga, N. Y.—Saratoga has a population of 12,000 to 60,000, according to the season of the year.

The filter beds handle 100,000 gals. per acre per day. The plant cost $200,000, including $65,000 for metering water supply and for

drains designed to separate the storm water. Some of the items of cost were:

Pumping plant	$11,000
Force main	24,500
Septic tanks	15,500
Filter beds	48,000
Total	$99,000

The operation of the pumps costs $700 per year.

The cost of maintenance of beds for 1907, according to figures secured on the ground, was $1,833.47, and for 1908, $1,153.07.

Mr. Barbour states that the total cost of maintenance per year amounts to about $3,000. Assuming the normal population at 12,000, a rate of 25 cts. per capita per year is indicated.

Septic Tanks and Contact Beds, Ballston Spa, N. Y.—Ballston Spa has a population of about 6,000, although being somewhat of a summer resort, the population varies. The plant was designed to deal with an estimated flow of 1,000,000 gals. per twenty-four hours.

No figures are in our possession as to expense of maintenance. The management, at the time of our visit, appeared to be in the hands of one man, who not only looked after the electrically driven pumps but the disposal works as well. Probably one man is all that is necessary for such a plant except in extraordinary occasions. The following is the cost of the plant as it appears in the accepted bid:

Septic tanks, beds, etc.	$39,456
Receiving tanks, pumping outfit	15,254
Pump house	3,072
Two gate houses	1,118
Force main ($1.68 per foot)	4,536
Sewer extension ($1.41 per foot)	1,551
Crushed stone ($0.90 per cubic yard)	18,000
Total	$82,987

Estimated Cost of Sewage Filtering.—Profs. C. E. A. Winslow and E. B. Phelps read a paper before the Boston Society of Civil Engineers, in 1907, wherein the following estimates were given of the probable cost of a 50-acre trickling or percolating sewage filter were given. It was estimated that 2,000,000 gals. per acre would percolate daily through a bed of broken stone 8 ft. thick. It was estimated that such filter could be built for $1,800,000, or $36,000 per acre, including all necessary land (Thompson's Island), grading, etc. The cost of treating the sewage was estimated thus per million gallons:

Capital charges	$3.50
Operation, including extra pumping	2.00
Chloride of lime	1.50
Total	$7.00

It is not stated what the land was estimated to cost.

Cost of Sewage Filters, Pawtucket, R. I.—Mr. George A. Carpenter gives the following relative to a sewage filter at Pawtucket, R. I.

The filter serves 7 miles of sewers, combined system, draining 960 acres, with a population of 9,500. These 7 miles of sewers deliver 58,000 gals. per day, as the average for the year (1895), more than half of this being ground water which enters the sewers, notwithstanding underdrains beneath of some sections of the sewers. There are 13 filter beds having a total filtering area of 2.36 acres; four of these beds (0.51 acres) being sludge beds, and receive the sewage from the bottom foot of the settling tanks. The two settling tanks are each 30 x 100 ft., 4 ft. deep. Sewage is held 24 hrs. in these tanks, and then delivered through 8-in. pipes to the filter beds in doses of 100,000 gals. to the acre. The underdrains are 4-in. tiles, buried 5 ft. deep in the natural sand that forms the filter beds. The cost of this plant was $12,000, or about $5,000 per acre of filter bed. One man operates the plant.

Cost of Sewage Filters, Waterloo, Ont.—Mr. Herbert J. Bowman gives the following relative to the cost of sewage filter beds built in 1895 for Waterloo, Ontario. The work was done by contract. Six filter beds were built, each averaging 132 x 200 ft., or 26,400 sq. ft., or a total of 3.65 acres, with an available filtering area of 3 acres. The land is of sand and gravel, requiring little leveling up. The beds are underdrained by 3-in. tiles, laid 10 ft. apart in a tile gutter composed of 5-in. half-tile, with joint covers of quarter-tile. The contract cost of 10,545 ft. of 3-in. tile in place (for 4 of the beds) was as follows:

Materials, 10,545 ft. at 2.5 cts.	$ 264
Laying 10,545 ft. at 3.5 cts.	369
1,856 cu. yds. gravel backfill at 20 cts.	371
Removing surplus earth	129
Total, 10,545 ft. at 10.75 cts.	$1,133

The trenches were dug 4 ft. deep, and backfilled with gravel which cost 20 cts. per cu. yd. delivered. The 3.5 cts. per lin. ft. for "laying" included digging the trench and backfilling, at which price the contractor barely paid his men, and had no profit.

The entire cost of the 6 beds, with 3 acres of filtering area, was:

3,050 cu. yds. excavation for embankments at 12 cts.	$ 366
1,500 cu. yds. gravel for leveling up beds at 20 cts.	300
15,800 lin. ft. 3-in. drain at 10¾ cts.	1,699
Sewer carriers (18-in.)	300
Total	$2,665

This is equivalent to only $900 per acre. The low cost is due to favorable conditions and to very low contract prices. The excavation for embankments was done with drag scrapers. The 3.6 acres of land cost $100 an acre in addition to the above cost.

Cost of a Sewage Filter and Septic Tank With Costs of Operation.*—Mr. F. A. Barbour gives the following relative to a sewage filter and septic tank plant at Saratoga Springs, N. Y., built in 1903.

**Engineering-Contracting*, July 14, 1909.

The sewage is lifted 15 ft. by three electrically driven centrifugal pumps (6-in.), and carried 8,800 ft. through a 16-in. cast-iron main, and then passed in succession through covered septic tanks, an aerator, an automatic dosing tank and intermittent sand filters. The volume ranges from 1,250,000 gals. to 2,500,000 gals. per day, the latter during the summer. The regular population is about 12,500, which increases to 50,000 during the summer.

The pumps and motors have an average combined efficiency of 35%. They cost $5,400. The pump, well and building cost $4,000. The pumps work only during the day. The 4 septic tanks are of concrete with a concrete vaulted roof, each being 52 x 91 ft. in area. The total capacity of the 4 tanks is 1,000,000 gals., the sewage being 8 ft. deep.

The aerator and dosing tank hold 26,000 gals.

There are 20 filter beds of about 1 acre each. About 2½ to 3 ft. of topsoil was excavated (and built into embankments) exposing the natural sand bed.

The cost of the plant was as follows (exclusive of a $40,000 storm water built to reduce the amount of sewage treated):

Pumping plant and accessories	$11,000
Force main (16-in.) 8,800 ft.	25,000
Septic tanks, 1,000,000 gals.	15,000
Filter beds, 20 acres	48,000
Total	$99,000

The cost of pumping and operating the purification works is $3,000 a year, of which $720 is for the electric power, and $600 covers all services at the screen and pumps. At the filter beds, $1,680 a year is spent, of which 66% is for work not relating to the maintenance of the surface of the filter bed, being trimming embankments, weeding drives, etc.

In midsummer 12 filter beds are used daily, the gates being changed twice; during the remainder of the year 8 beds are used daily, the gates being shifted once. The average daily amount of sewage per bed in use is about 140,000 gals., applied in four doses. All the filter beds are kept in commission and the beds are used alternately, so that the average daily rate for the field is 60,000 gals. per acre. Mr. Barbour believes that double this rate could be maintained with equally good results.

Assuming a cost of $3,000 per year for operation and $5,000 per year (5% of $100,000) for capital charges, we have a total of $8,000 per year, to which may be added, say, $1,000 for repairs and depreciation of pumping plant, making a grand total of $9,000, or less than $30 a day for treating 1,2000,000 gals., or about $25 per million gals.

Cost of Cleaning Sewers and Catch Basins.*—Mr. Allen Aldrich gives the following relative to the cost of cleaning 178 miles of

*Engineering-Contracting, Aug. 11, 1909.

sewers at Providence, R. I., during 1898. There were in use 4,026 catch basins (23¼ per mile), each of which was cleaned, on an average, 3½ times during the year. The 14,522 cleanings yielded 10,600 cu. yds. of deposit, or about 0.7 cu. yd. per cleaning. A gang of 2 laborers and 2 one-horse carts with drivers averaged 20 cu. yds. per day, cleaned out and hauled away. Assuming men's wages to be $2 each and a horse to be $1, the daily wage of this gang would be $10, and the cost would be 50 cts. per cu. yd. of sludge, or 35 cts. per catch basin per cleaning. The labor cost for the year would then be about $300 per mile of sewer, since 600 cu. yds. were removed per mile.

In addition to this, about 10.4 miles of sewers were flushed out with a fire hose during the year, yielding 831 cu. yds. more.

In cleaning the catch basins a man descends into the basin and first bails out the water into the sewer, until nothing but sludge is left; and the sludge is removed with buckets raised by a "wheel derrick" (a tripod with a drum operated by the wheels on which the derrick is transported) and dumped into the cart. Steel carts holding 1 cu. yd. are used.

Mr. T. Chalkley Hatton describes a more economic method of cleaning catch basins, which involves a special design of catch basin, so that the sludge accumulates in a "catch bucket." This galvanized catch bucket is 3 ft. high and 2½ ft. diam. at the top. A cast-iron hood is placed over the outlet to the sewer, for trapping the sewer gases. This hood is removed before raising the catch bucket. Riveted to the top of the bucket is an angle iron that rests on a ledge in the catch basin, the joint being merely dirt proof and not water proof. The bucket is raised with a "wheel derrick" (a trip on wheels), by means of a friction pulley. The legs of the derrick are of gas pipe.

A brick catch basin (8 ft. 8 ins. deep) on a 6-in. concrete foundation, with a bucket, hood, and connections complete, costs $40. Each connecting inlet costs about $35. The "wheel derrick" costs $35. Two men, with a horse and cart, can clean 20 catch basins a day, at a cost of 25 cts. per catch basin.

Cost of Flushing Sewers.*—Mr. Andrew Rosewater gives the following relative to the cost of flushing sewers by automatic flush tanks and by hand. The costs are estimated, but said to be based upon actual performance.

In 1893 Mr. Rosewater designed flush tanks that averaged 400 gals. capacity each and discharged at the rate of 11 gals. per second, developing effective scour in an 8-in. sewer for a distance of 2,000 ft. below the tank. To avoid sedimentation in the pipe that serves the flush tank, Mr. Rosewater states that the velocity of flow should not be less than 2 ft. per sec., and this is attained in a ¼-in. pipe discharging 445 gals. in 24 hrs. A larger pipe causes decreased velocity and sedimentation where unfiltered water

---

**Engineering-Contracting*, July 28, 1909.

is used. He estimates the cost of maintenance and operation of each flush tank as follows per annum, provided the flush tank is properly designed:

Interest on $100 tank at 5 per cent	$ 5.00
Water, 182,000 gals. at $15 per million	2.73
Labor of attendance ($2,000 ÷ 300 tanks)	6.67
Total per tank per year	$14.40

Two men with a horse and wagon (costing $2,000 per year) are estimated to be able to take care of 300 flush tanks and maintain them in repair.

In 100 miles of sewers in Omaha, Mr. Rosewater found that the existing flush tanks were using 1,800,000 gals. daily, which was three times the amount needed if the flow had been properly adjusted.

If flushing is done by hand labor, there are three methods available: (1) Water carts; (2) direct portable base connections to hydrants; and (3) connection with pipe mains and hand valves.

Flushing with water carts requires two men, at $1.50 each, and two horses, at $0.75 each, to handle 25 tanks per day, or 18 cts. per tank per day, or $65.70 per tank per year, to which must be added $2.73 for the water, making a total of $68.43.

Flushing with portable base requires 2 men and a horse, who handle 30 tanks daily, at a cost of $49.25 per year per tank, to which must be added $2.73 for water, making a total of $49.25.

Flushing with pipe connection and hand valves requires the construction of a manhole, which, with connections, etc., will cost $100. One man with a horse and wagon can handle 40 tanks daily, at a cost of $22.50 per tank per year. To this must be added $5 for interest and $2.73 for water, making a total of $30.25.

Cost of Vitrified Conduits and of Tile Drains, Cross-References.— Data on these subjects will be found in Section XV, Miscellaneous Cost Data.

SECTION IX.

PILING, TRESTLING AND TIMBERWORK.

Definitions.—Consult the index for words not found in the following alphabetical list

Adz.—A carpenter's chipping tool, like a small hoe with a handle.

Angle Block.—A block of cast iron or wood, having a triangular cross-section, against which the braces and counters of a Howe bridge truss abut.

Apron.—A covering at the foot of a spillway, to protect the ground from scour.

Balk.—A large stick of timber.

Batter Piles.—Piles driven inclined, as distinguished from plumb piles.

Bent.—One of the transverse frames of a trestle which supports the "deck" or floor system. It consists of a sill, a cap, posts (vertical and batter), and sway braces. A pile bent consists of the piles, cap and sway braces.

Bit.—The part of an auger that does the boring.

Block and Tackle.—A pulley block and rope.

Board Measure.—The unit of timber measure is the board foot (ft. B. M.), which is 1 ft. square and 1 in. thick, or 1/12 cu. ft. A thousand feet board measure (1,000 ft. B. M.) is often designated by the letter M.

Box Culvert.—A culvert having a water way of rectangular cross-section.

Brace.—A diagonal compression member of a truss, also any stick used to resist compression, like the horizontal timbers running from one side of a trench to another. Sway braces are the diagonal braces of a trestle bent. Lateral (or wind) braces are the diagonal braces between the lower, or the upper, chords of a Howe truss bridge.

The frame that holds a bit or auger is called a brace.

Brad Spike.—A railway spike.

Brash.—Brittle.

Bridging.—The small diagonal braces between two joists or stringers of a floor system, which prevent the joists from turning over on their sides, or from buckling laterally.

Brush Hook.—A curved blade, mounted on a wooden handle, used for cutting brush.

Burnettizing.—Impregnating the pores of wood with a solution of zinc chloride under pressure.

Burr.—The nut of a bolt.

Calk.—To fill joints with oakum, or the like, to prevent leakage.

Cant.—To tip or lean.

Cant Hook.—A tool for handling timber. It is like a peavey, except that the pole or handle is not pointed.

Cap.—A timber across the tops of posts or piles, and usually driftbolted thereto.

Centers.—The falsework that supports an arch during construction, or, more strictly, the arch ribs of this falsework.

Check.—A crack in timber due to shrinkage from seasoning.

Clear Inspection.—A class of timber conforming to some such specification as follows (N. Y. Lumber Assoc.):

"Scantling and plank shall be free of sap, large knots or other defects. Dimension sizes shall be free from sap, large or unsound knots, shakes through or round."

Clearing.—The removal of all trees and brush above the ground level. The removal of the roots below the ground level is grubbing.

Close Piles.—Sheet piles.

Corbel.—A projecting beam acting as a cantilever supporting another beam.

Cord.—A cord of wood measures 4 x 4 x 8 ft., or 128 cu. ft.

Corduroy.—A road made of round or split logs laid side by side upon marshy ground.

Creosoting.—Impregnating the pores of timber with hot creosote (dead oil of coal tar) under pressure.

Crib.—A log cabin structure built of timbers whose ends are notched and drift bolted together.

Dap.—A notch cut into the side of a stick of timber.

Deck.—The wooden floor system of a railway bridge, consisting of the stringers, cross-ties and guard rails.

Deciduous.—Subject to shedding leaves in the fall and winter, as distinguished from evergreen.

Docking.—A retaining wall of piles sheeted with plank, and capped with a "dock stick" bolted thereto.

Dolly.—A roller upon which is mounted a small truck for carrying timber.

Dimension lumber.—Sticks measuring 6x6 ins. and larger.

Dosey.—Sap rotted.

Dovetail.—A timber joint made by cutting the end of a stick so that it is narrower a few inches back of the end, and is let into a cross timber notched to fit it.

Dowel.—A short iron pin inserted into bored holes in two faces of sticks that meet. Usually a dowel is used to hold the foot of a trestle post from displacement from the sill on which it rests.

Dressed.—Planed.

Drift bolt.—A bar of round iron (¾ to 1 in.) used like a large nail (without a head) to fasten timbers together. An auger hole, 1/16 to ¼ in. smaller than the drift bolt, is first bored and the bolt is driven in the hole.

Drop Timbers.—Timbers dropped into place to close an opening in a dam.

Dry rot.—Rotting of timber not exposed to rain. The moisture is supplied by the sap of the timber. Dry rot often occurs when green timber is painted, the paint preventing the evaporation of the sap.

Dubb.—To cut the end of a stick to a bevel around the edge. It is usually good practice to dubb the end of a pile preparatory to ringing it.

Falsework.—The temporary frame work or staging built to support a bridge or other structure during its erection.

Fascine.—A bundle of brush or small branches wired or tied together.

Flume.—A trough for carrying water.

Follower.—A short length of pile placed on top of the pile that is being driven, to protect it from the blows of the hammer, or to force it down below the bottom of the leaders as when driving under water.

Forms.—The mold in which concrete is cast.

Frame.—To shape the members of a timber structure. Sometimes the term is used to include the erection and fastening together of the members.

Frap.—To bind together with a rope.

Gib or Gib Plate.—A large flat plate of wrought iron or steel, used like a washer between the timber and the nut heads of rods in a Howe truss.

Gin or Gin Pole.—A mast with a pulley at the top, guyed with three or four ropes, and used to raise heavy timbers, etc.

Gins.—See Leads.

Grillage.—Timbers laid criss cross, bolted together and fastened by drift bolts to the heads of foundation piles.

Grub.—To remove the roots of trees and brush.

Jetting Piles.—To sink piles by means of a water jet.

Joist.—A beam or stringer that supports flooring.

Kerf.—The narrow slot made in sawing timber.

Kiln Dried.—Dried artificially in a kiln.

Knot.—The American Society for Testing Materials adopted (1906) the following definitions: (1) A *sound knot* is one which is solid across its face and which is as hard as the wood surrounding it; it may be either red or black, and is so fixed by growth or position that it will retain its place in the piece. (2) A *loose knot* is one not firmly held in place by growth or position. (3) A *pith knot* is a sound knot with a pith hole not more than ¼ in. in diameter in the center. (4) An *encased knot* is one which is surrounded wholly or in part by bark or pitch. Where the encasement is less than ⅛ of an inch in width on both sides, not exceeding one-half the circumference of the knot, it shall be considered a sound knot. (5) A *rotten knot* is one not as hard as the wood it is in. (6) A *pin knot* is a sound knot not over ½ in. in diameter. (7) A *standard knot* is a sound knot not over 1½ in. in diameter.

(8) A *large knot* is a sound knot, more than 1½ in. in diameter. (9) A *round knot* is one which is oval or circular in form. (10) A *spike knot* is one sawn in a lengthwise direction; the mean or average diameter shall be considered in measuring these knots.

Lagging.—The plank sheeting placed upon the frames of arch centers.

Lag Screw.—A thick screw with a square bolt head.

Leads or Leaders.—The vertical guides that guide a pile driver hammer during its rise and fall. Also called gins, ways, etc.

Lug Hook.—A timber grapple, much like ice tongs hung from the center of a wooden handle; used for carrying timber, one man at each end of the handle.

Mattock.—A grubbing tool with one cutting edge shaped like an adz (or hoe), and the other edge like an ax or pick.

Mattress.—A brush mattress consists either of fascines bound together, or of strands of brush woven together, ballasted with stone and sunk in a river bed to prevent scour.

Merchantable Timber.—According to specifications of the Southern Lumber and Timber Asso.: "Scantling shall show three corners heart free from injurious shakes or unsound knots. Plank nine inches and under wide, shall show one heart free and two-thirds heart on opposite side; over nine inches wide shall show two-thirds heart on both sides, all free from round or through shakes, large or unsound knots. Dimension sizes: All square lumber shall show two-thirds heart on two sides and not less than half heart on two other sides. Other sizes shall show two-thirds heart on faces and show heart two-thirds of the length on edges excepting where width exceeds thickness by three inches or over, and then it shall show heart on the edges for half its length. All stock to be well and truly manufactured full to size and saw butted."

Miter.—The joint between two beveled edges, the bevel usually being 45 degrees.

Mortise.—A hollow cut made in the side of a timber to receive the tenon or tongue on the end of another timber.

Mud Sills.—Short pieces of timber (often cedar) laid beneath the sill of a trestle bent to keep it from contact with the ground.

Needle Beam.—Floor beam of a Howe truss, through the ends of which pass the vertical rods.

Nippers.—The scissor-like tongs that clutch the hammer of a free-fall pile driver.

Overhang Driver.—See Pile Driver.

Packing Piece.—A piece of wood or metal placed between two timbers to prevent their coming in contact.

Peavey.—A pointed pole with a pivoted hook near the pointed end, used for handling timbers. See Cant Hook.

Pile.—A stick driven into the earth. *Foundation* piles are driven to support a bridge, building or other structure. *Sheet* piles are sawed timber piles driven touching one another, so as to form a tight diaphragm. *Wakefield* piles are sheet piles made by bolting

or spiking three planks together, so as to form a tongue and groove. When driven, this gives a triple lap sheet piling.

Pile Driver.—A *free-fall* pile driver has a hammer held by nippers which, when tripped, allow the hammer to fall freely. A *friction clutch* driver has its hammer always attached to the hoisting rope, which is operated by the drum with a friction clutch. A *steam hammer* is raised by steam acting directly upon a piston attached to the hammer. An *overhang* driver is one mounted in a frame whose leads project 8 to 20 ft. beyond the base of support.

Pinch Bar.—A steel bar with a chisel-shaped end.

Pitch Pocket.—The American Society for Testing Materials gives the following specification: *Pitch pockets* are openings between the grain or the wood containing more or less pitch or bark. These shall be classified as small, standard and large pitch pockets. (a) A small pitch pocket is one not over ⅛ of an inch wide. (b) A standard pitch pocket is one not over ⅜ of an inch wide, or 3 ins. in length. (c) A large pitch pocket is one over ⅜ of an inch wide, or over 3 ins. in length. A *pitch break* is a well-defined accumulation of pitch at one point in the piece.

Plank.—In the lumber trade, the term plank is applied to pieces 1½ to 5 ins. thick x 7 ins. wide, or wider.

Posts.—The upright members in a trestle bent.

Put Logs.—Horizontal stringers supporting a building scaffolding, the ends being inserted in put-log holes left in the masonry.

Rangers.—The longitudinal timbers used in bracing a trench; the "braces" being the cross timbers between the rangers.

Revetment.—A river bank protection.

Ring.—An iron band around the head of a pile to protect it from splitting or brooming.

Scantling.—A timber of small cross-section. Also the cross-section dimensions, as a "scantling" of 4 x 10 ins.

Scarf Joint.—A joint made by overlapping and bolting or locking together the ends of two pieces of timber that are halved, notched or cut away, so that they will fit each other and form a lengthened stick of the same size at the scarf joint as elsewhere.

Scissors.—See Nippers.

Seasoned.—Air dried.

Sheet Piles.—See Piles.

Shoe.—An iron point over the lower end of a wooden pile.

Sill.—The horizontal timber of a trestle bent on which the posts rest.

Sheeting or Sheathing.—Plank or boards forming a wall, or a diaphragm.

Skeleton Bracing.—Trench bracing consisting only of rangers and cross braces, without any plank sheeting.

Stay Lathed.—Temporarily fastened with small cleats or braces.

Stringer.—A longitudinal joist in a floor system.

Studs.—The vertical pieces of timber (in a building) to which sheeting is fastened.

Stumpage.—The amount paid a land owner for standing timber.

Tenon.—A projecting tongue cut on the end of a stick of timber. See Mortise.

Tongs.—See Nippers.

Treated.—Preserved by impregnation with creosote, zinc chloride, or the like.

Trestle.—A bridge consisting of bents supporting a floor system. A *frame* trestle consists entirely of sawed timber. A *pole* trestle is made largely of round poles, none of which, however, are used as piles. A *pile* trestle has bents composed of piles. See Bent.

Wakefield.—See Pile.

Wale.—A longitudinal timber bolted to a row of piles; but not on top of the piles, such a timber being a cap.

Water Jet.—See Jetting.

Ways.—See Leads. Also the inclined timbers down which any structure is launched into the water.

Importance of Timberwork.—Although timber will be used to a less and less extent for permanent engineering structures, it will long have a wide field of usefulness for falsework, forms, centers, temporary trestles, etc. In foundations that are always under water, timber will doubtless never cease to be used to a considerable extent. In supporting the roofs of mining excavations timber may never cease to be used. Trestle bridges for railways are still built extensively in the West, and even in the East. In brief, there is and long will be an enormous amount of timber used annually in engineering construction. It is a serious mistake, therefore, to regard a knowledge of timberwork as being comparatively non-essential to the engineer of the future.

Measurement of Timberwork.—Timber is sold by the 1,000 ft. B. M. (thousand feet board measure). A common abbreviation for 1,000 ft. B. M. is the letter M. One foot board measure is 12 ins. square and 1 in. thick, which is one-twelfth cubic foot. To estimate the number of feet board measure in a sawed stick, multiply the end dimensions (in inches) together and divide by twelve, then multiply this quotient by the length of the stick (in feet). For example, in a 10 x 12-in. stick, 16 ft. long, there are:

$$\frac{10 \times 12}{12} \times 16 = 160 \text{ ft. B. M.}$$

Timberwork is paid for at a specified price per M for the timber measured in the work. The contractor must be cautious to make allowance for wastage in framing the timber. Scarf joints, for example, may cause a wastage of 6%. If bridge flooring planks are laid diagonally for a 16-ft. roadway, there is a wastage of about 5% when the ends are sawed off on line with the outer stringers.

Timber is usually sold in lengths containing an even number of feet, as 10, 12, 14, 16 ft. In examining plans, the contractor should be careful to note whether the dimensions are such as to require the use of even lengths or not, for a careless engineer or architect may so design a structure as to cause a large wastage of timber.

In measuring dressed lumber, remember that the thickness used in calculating the number of board feet is not the actual thickness of the dressed board, but the thickness of the original stock from which the dressed board was made. So also the width of a tongue and grooved board is not its actual face width, as laid, but it is the width of the original board.

Cubic Contents and Weight of Piles and Poles.—Table I gives the cubic feet contents of a tapering pole. Thus a pole 8 ins. diam. at the small end and 16 ins. at the large end, contains 0.81 cu. ft. per lin. ft. of pole (see Table I). Hence if the pole is 30 ft. long, it contains $30 \times 0.81 = 24.3$ cu. ft. of timber.

The weight of timber per cubic foot is given below.

In estimating the amount of lumber that can be sawed from a log, the following rule is used:

From the least diameter in inches subtract 4, divide by 16, multiply by the length in feet, and the quotient is the number of feet board measure.

Expressed as a formula, we have

$$\text{Ft. B. M.} = \left(\frac{d-4}{16}\right) d\, L.$$

Weight of Timber.—The cost of hauling timber must frequently be estimated. Timber is bought by the M, and it is well to remember that an M contains $83\frac{1}{3}$ cu. ft., which at a specific gravity of 1 (the same as water) would be 5,200 lbs., or 2.6 tons per M. However, only very dense, green oaks, and similar dense timber, ever have a specific gravity equal to 1.

Table II gives the weight of timber for different specific gravities.

The following is the specific gravity of some of the common kinds of timber:

	Green.	Kiln Dried.
Yellow pine (Southern)	0.90	0.60
Norway pine (Northern)	....	0.50
Douglas fir	0.65	....
White pine	....	0.40
White oak	1.00	0.70
Hemlock	0.60	0.50
Cedar	....	0.35

See Frye's "Civil Engineer's Pocketbook" for the most complete data on weights of wood.

TABLE II.—WEIGHT OF TIMBER PER CU. FT. AND PER M FT. B. M.

Specific gravity.	Weight per cu. ft., lbs.	Weight per 1,000 ft. B. M., lbs.
1.0	62.40	5,200
0.9	56.16	4,680
0.8	49.92	4,160
0.7	43.68	3,640
0.6	37.44	3,120
0.5	31.20	2,600
0.4	24.96	2,080
0.3	18.72	1,560

TABLE I.—CU. FT. OF WOOD PER LIN. FT. OF PILE OR POLE.

Large Diam. ins.	Small Diameters (in inches). 6 ins.	6½ ins.	7 ins.	7½ ins.	8 ins.	8½ ins.	9 ins.	9½ ins.	10 ins.	10½ ins.	11 ins.	11½ ins.	12 ins.	12½ ins.	13 ins.	Large Diam. ins.
8 ins.	.27	.29	.31	.33	...	...	...	...	...	...	...	...	...	...	...	8 ins.
8½ ins.	.29	.31	.33	.35	.37	...	...	...	...	...	...	...	...	...	...	8½ ins.
9 ins.	.31	.33	.35	.37	.39	.42	...	...	...	...	...	...	...	...	...	9 ins.
9½ ins.	.33	.35	.37	.40	.42	.44	.47	...	...	...	...	...	...	...	...	9½ ins.
10 ins.	.36	.38	.40	.42	.44	.47	.49	.52	...	...	...	...	...	...	...	10 ins.
10½ ins.	.38	.40	.42	.45	.47	.49	.52	.54	.57	...	...	...	...	...	...	10½ ins.
11 ins.	.41	.43	.45	.47	.50	.52	.55	.57	.60	.63	...	...	...	...	...	11 ins.
11½ ins.	.43	.45	.48	.50	.52	.55	.58	.60	.63	.66	.69	...	...	...	...	11½ ins.
12 ins.	.46	.48	.50	.53	.55	.58	.61	.63	.66	.69	.72	.75	...	...	...	12 ins.
12½ ins.	.49	.51	.53	.56	.58	.61	.64	.66	.69	.72	.75	.78	.82	...	...	12½ ins.
13 ins.	.52	.54	.56	.59	.61	.64	.67	.69	.72	.75	.79	.82	.85	.89	...	13 ins.
13½ ins.	.55	.57	.59	.62	.64	.67	.70	.73	.76	.79	.81	.85	.89	.92	.96	13½ ins.
14 ins.	.58	.60	.62	.65	.68	.70	.73	.76	.79	.82	.86	.89	.92	.96	.99	14 ins.
14½ ins.	.61	.63	.66	.68	.71	.74	.77	.80	.83	.86	.90	.93	.96	1.00	1.03	14½ ins.
15 ins.	.64	.66	.69	.72	.74	.77	.80	.83	.86	.90	.93	.96	1.00	1.03	1.07	15 ins.
15½ ins.	.67	.70	.72	.75	.78	.81	.84	.87	.90	.93	.97	1.00	1.04	1.07	1.11	15½ ins.
16 ins.	.71	.73	.76	.79	.81	.84	.87	.91	.94	.97	1.01	1.04	1.08	1.11	1.15	16 ins.
16½ ins.	.74	.77	.79	.82	.85	.88	.91	.94	.98	1.01	1.04	1.08	1.12	1.15	1.19	16½ ins.
17 ins.	.78	.80	.83	.86	.89	.92	.95	.98	1.02	1.05	1.08	1.12	1.16	1.19	1.23	17 ins.
17½ ins.	.81	.84	.87	.90	.93	.96	.99	1.02	1.06	1.09	1.13	1.16	1.20	1.24	1.28	17½ ins.
18 ins.	.85	.88	.91	.94	.97	1.00	1.03	1.06	1.10	1.13	1.17	1.21	1.24	1.28	1.32	18 ins.
18½ ins.	.89	.92	.95	.98	1.01	1.04	1.07	1.11	1.14	1.18	1.21	1.25	1.29	1.33	1.37	18½ ins.
19 ins.	.93	.96	.99	1.02	1.05	1.08	1.11	1.15	1.18	1.22	1.26	1.29	1.33	1.37	1.41	19 ins.
19½ ins.	.97	1.00	1.03	1.06	1.09	1.12	1.16	1.19	1.23	1.26	1.30	1.34	1.38	1.42	1.46	19½ ins.
20 ins.	1.01	1.04	1.07	1.10	1.13	1.17	1.20	1.24	1.27	1.31	1.35	1.39	1.43	1.47	1.51	20 ins.

Cost of Manufacturing Lumber.—A contractor will often find it profitable to cut and saw lumber. A 20-hp. portable engine will run a small sawmill, and with a crew of 5 men the output will be about 8,000 ft. B. M. of 3-in. plank per day. If the wages of the 5 men are $10 a day, and the rental of the engine and saw is $10 more per day, the cost of sawing is about $2.50 per M. The price of the timber as it stands before cutting, is called the stumpage price, and this ranges from $1 to $5 per M. The cost of cutting and skidding hemlock logs, I have found to be about $1 per M, half of which is for cutting and the other half for skidding, wages being $1.50 a day. The total cost of sawed plank in one case was as follows:

	Per M.
Stumpage	$1.50
Cutting	0.40
Skidding	0.60
Sawing	2.50
Total per M.	$5.00

I have been told by a lumberman in Washington that his "logging" cost him $5 per M, wages of laborers oeing $3 per day. This seems like a high cost. It includes cutting the trees and dragging the logs to an incline up which they are hauled by a hoisting engine to a chute, down which they are slid by gravity to tidewater.

Cost of Sawing and Planing Lumber.*—In connection with the operation and care of the Muscle Shoals Canal, U. S. Government Tennessee River Improvement, a small sawmill was used for sawing and planing lumber. This lumber was largely used in building and repairing boats and was usually sawed and planed just as needed. Consequently the mill was run very spasmodically, sometimes being in operation all day, and again only an hour or so. The men operating the mill were used on other work when not employed in the mill. The sawyer was paid $50 per month and helpers from $1.20 to $1.50 per day of 8 hrs.

During the year 1904-5 a total of 77,591 ft. B. M. of lumber were sawed at an average cost of $2.11 per M, and 56,121 ft. B. M. were planed at an average of $1.38 per M.

The lumber ranged in size from 8 ft. to 45 ft. long and from 1-in. boards to sticks 20-in. x 20-in. in cross-section.

The planer, which would take a stick as large as 6 x 24 ins., was worked by the same operations as the sawmill.

The mill was run by a 55-hp. Victor turbine and had a 60-in. circular saw.

Price of Yellow Pine for Fourteen Years.†—The "American Lumberman," Aug. 22, 1908, gives a very complete table of prices of Southern yellow pine lumber of different classes, from which we have selected the prices of two classes only. These prices apply to lumber delivered at points that are reached by a 23-ct. rate (per

*_Engineering-Contracting_, Aug. 29, 1906.
†_Engineering-Contracting_, Sept. 2, 1908.

100 lbs.) from the mills, and include the 23-ct. freight rate. The prices are as follows:

Year.	No. 1 Dimension 2" x 10" — 16'.	Timbers 4" x 10" to 12" x 12" — 16'.
1894	$12.50	$16.25
1895	12.25	16.25
1896	11.00	15.50
1897	12.50	16.00
1898	13.50	17.00
1899	13.50	17.75
1900	14.50	19.25
1901	15.50	20.00
1902	16.00	20.50
1903	16.00	20.50
1904	16.00	21.00
1905	17.50	23.25
1906	21.00	28.00
1907	22.25	28.25
1908	17.75	25.25

Life of Trestle and Bridge Timbers.*—A committee of the American Railway Bridge and Building Association reported in 1908 that the following is the average life:

	Years.
Caps of Trestles:	
Long leaf pine (av. of 12 rys.)	10
Douglas fir (av. of 8 rys.)	10
White or burr oak (av. of 2 rys.)	11
Stringers:	
Long leaf pine (av. of 13 rys.)	10
Douglas fir (av. of 10 rys.)	11
White oak (av. of 1 ry.)	10
White pine with iron cover (1 ry.)	14
Ties:	
Long leaf pine (av. of 10 rys.)	9
Douglas fir (av. of 4 yrs.)	12
White oak (av. of 4 rys.)	10
Piles:	
White or burr oak (av. of 10 rys.)	10
White cedar (av. of 6 rys.)	17
Red cedar (av. of 2 rys.)	12
Treated pine (av. of 2 rys.)	14

In 1899 a committee of the same association made a similar report, of which the following is an abstract. It is not so reliable as the report above given.

The life of piles is as follows:

	Years. In water.	Years. On land.
Cedar, white (Wis.)	....	20+
Cedar (Wis.)	28	16 to 20
Chestnut (New England)	15 to 20	12 to 18
Cypress (Ill.)	....	7
Oak (New Eng.)	9 to 20	8 to 14
Oak, white (Middle States)	8 to 30	8 to 12
Pine, yellow (Miss.)	10	10
Pine, Norway (Wis.)	7	6
Spruce (New Eng.)	4 to 10	4 to 8
Spruce, red (Colo.)	10 to 15	7 to 10
Tamarack (New Eng.)	18	10 to 12
Tamarack (Wis.)	....	8

Engineering-Contracting, Nov. 25, 1908.

The life of unprotected bridge timber, whether in stringers, bents, or trusses, is as follows:

	Years.
Pine, yellow long leaf (New Eng.)	12 to 20
Pine, yellow long leaf (Miss.)	8
Pine, yellow long leaf (Ill.)	8 to 14
Pine, yellow long leaf (Colo.)	10
Pine, white (New Eng.)	10 to 18
Pine, white (Ill.)	10 to 14
Pine, white (Minn.)	10
Pine, Colorado	8 to 15
Pine, Norway (Wis.)	8 to 10
Spruce (New Eng.)	5 to 10
Douglas fir (Wyo.)	10 to 16
Douglas fir (Colo.)	18 to 20
Oak, white (Ohio)	7 to 8
Oak, white (Ill.)	14 to 18
Cypress, red (Ala.)	12

Even a casual study of these figures shows that many of them are merely rough guesses. For example, why should white oak timber in Illinois last twice as long as in Ohio. The reports for these two states are from different superintendents, which accounts for the discrepancy.

The life of timber truss bridges protected from the weather was reported to be 20 to 50 years, several superintendents saying indefinitely.

Consult the section on Railways for life of timber, particularly ties.

Life of Treated and Untreated Fence Posts.—A committee of the Am. Ry. Engrg. and Mn. of Way Assoc. reported in 1907 that the average life of fence posts is as follows:

Chestnut and oak	9 years
Locust	10 years
Catalpa	12 years
Cedar	15 years
Bois d'Arc	Everlasting

Mr. B. E. Buffum made some experiments in Wyoming with 80 pitch-pine fence posts, by treating them in three different ways. The posts were placed in 1891 and in 1907 the following conclusions were reached. The best treatment consisted in dipping the lower 2½ ft. of post in California (?) crude asphaltic oil and then burning off the outside oil. This drives the hot oil into the post and chars the outside. After 16 years these posts seemed good for a life of fully 30 years, as they were as sound as the day they were placed.

Of 15 untreated posts the life was estimated as follows:

Number.		Estimated life, years.
4		12
2		14
4		16
3		17
1		18
1		20+
15	Average.	15

A treatment of the lower 2½ ft. of the post with tar was less effective than with crude oil, and it seemed to make little difference whether the tar was burned off or not. Of ten posts thus treated 8 appeared to be good for a life of 20 years or more.

Posts simply well charred seemed good for a life of about 20 years.

For cost of fences see the sections on Railways and on Miscellaneous Costs.

Life of Creosoted Ties.—In 1880-2, some 150,000 ties were creosoted with 10 lbs. of oil per cu. ft. and put in the tracks of the Houston and Texas Central Ry. In 1907, there were still 11,300 in service, and Mr. O. Chanute estimated that the average life had been 19.35 years.

Cost of Treating Timber, Cross References.—The steadily advancing price of timber has lead to "treating" timber with preservatives, such as creosote and zinc chloride.

Cedar may be regarded as a timber containing a natural preservative—the oil of cedar, which is too often "killed" by kiln drying to reduce the weight before shipment.

In addition to the data in the following pages, consult that part of the section on Railways relating to tie preservation. See the index under "Timber, Preserving."

Process Treatment of Timber and Approximate Costs.*—Mr. G. B. Shipley is author of the following:

The evolution of timber preserving processes in this country within the last ten years has developed many new methods of treating ties, piling, timber, poles, crossarms, mine timbers, etc., and a great many antiseptics or compounds are being proposed, but the subject is of such vital importance that the leading organizations are backward about experimenting. Consequently the processes actually employed may be subdivided into only two methods and these are the full cell and partial cell treatments. The full cell treatment consists of impregnating the wood fibres and filling the cells with the antiseptic, whereas the partial cell treatment consists of impregnating the wood fibers only. These two methods are sometimes confused with processes or the manner in which the treatment is performed.

The treatment of wood depends upon where the wood will be used, the climatic conditions, the permissible cost of treatment and the wood structure. If first-class wood is to be used for such work as docks around salt water, telegraph poles, building foundations or for railroad ties, where there is no mechanical wear, the full cell method is best, but if the wood is soft and not protected from mechanical wear, then the partial cell method will be satisfactory for the reason that with the latter method the chemical life will be equivalent to the mechanical life.

---

*Engineering-Contracting, Jan. 19, 1910.

The important processes that are in use in this country and which may be classed under the full cell method are the burnettizing, Wellhouse, full cell creosote and card processes, and those which may be classed under partial cell method are the Reuping, Lowry and absorption processes. These processes, with the exception of the absorption process, are manipulated by mechanical contrivances, such as pressure pumps, vacuum pumps and air compressors and can be controlled to suit the wood structure, while with the absorption process the treatment is governed by temperature and atmospheric pressure, therefore is limited to certain woods.

Burnettizing Process.—This is often referred to as the zinc chloride process and consists of impregnating the wood fibers with a solution containing ½ lb. of dry zinc chloride per cubic foot of wood and is operated as follows: The wood is first air seasoned in the open, or steamed in retorts to expel the moisture, then a vacuum is produced and maintained until the solution is introduced and the wood is completely submerged, the pressure is then increased to about 100 lbs. or 125 lbs. per sq. in., by pumping in additional solution until the required penetration and impregnation is obtained, when the solution is drained from the retort. The approximate time required for the process is:

	Hrs.	Mins.
Steaming to 20 lbs. pressure	0	30
Steaming, 20 lbs. to 35 lbs. pressure	3	30
Blowing off steam	0	15
Vacuum	0	45
Solution to about 100 lbs. pressure	0	45
Solution maintained to 100 lbs. pressure	1	15
Forcing back solution	0	15
Total cycle	7	15

If the steaming time is reduced 2 hrs., then the total cycle is 5 hrs. 15 mins.

Wellhouse Process.—This is often referred to as the zinc tannin process. It consists of impregnating the wood fibers with a hot solution containing about ½ lb. of dry zinc chloride plus ½% of glue or gelatine per cubic foot of wood, then following by injecting a second solution containing ½% of tannic acid. The purpose of the tannin is to solidify the first injection to prevent leaching.

The wood is first air seasoned in the open or steamed in retorts to expel the moisture, then a vacuum is produced and maintained until the solution is introduced and the wood is completely submerged, the pressure is then increased to about 100 to 125 lbs. per sq. in. by pumping in additional solution until the required penetration and impregnation are obtained, when the solution is drained from the retort and the second movement takes place by filling the retort with a solution containing tannic acid and increasing the pressure by pumping in additional solution at about 100 or 125 lbs. per sq. in. until the required penetration is obtained, when the solution is drained from the retort. The approximate time required is:

	Maximum Hrs.	Time, Mins.
Steaming to 20 lbs. pressure	0	30
Steaming, 20 to 35 lbs. pressure	3	30
Blowing off steam	0	15
Vacuum	0	45
Solution and glue to 100 lbs. pressure	0	45
Solution and glue maintained at 100 lbs. pressure	1	15
Forcing back solution and glue	0	15
Tannin introduced to 100 lbs. pressure	0	20
Tannin maintained at 100 lbs. pressure	0	50
Forcing back tannin	0	15
Total cycle	8	40

If steaming time is reduced 2 hrs., then the total cycle equals 6 hrs. 40 mins.

Absorption Process.—This is often referred to as the non-pressure process consists of submerging the wood in a boiling preservative at a temperature of from 180° to 230° F., then following with a cold preservative as follows: The wood is first air seasoned in the open to reduce the moisture, then placed in either an open or closed receptacle where it is submerged in a hot preservative which expels the air and additional moisture; the receptacle is then drained and the wood submerged in a cold preservative. The first movement opens the pores or cells of the wood forming a vacuum within, while the second movement causes absorption due to the difference in temperature and atmospheric pressure. This process can be used in either open tanks or closed retorts. For treating the butts of poles, fence posts, piling and small quantities of ties the open tank is satisfactory, but for treating large quantities of material the closed retort is recommended where thorough impregnation is desired. The time of treatment is as follows:

Green Timber.

Boiling in hot preservative from 8 to 10 hrs.
Bath in cold preservative from 8 to 16 hrs.
Total time of treatment, 16 to 26 hrs.

Seasoned Timber.

Boiling in hot preservative from 3 to 6 hrs.
Bath of cold preservative from 4 to 8 hrs.
Total time of treatment, 7 to 14 hrs.

With this process it is possible to impregnate a limited class of woods with about 6 to 12 lbs. of concrete oil per cubic foot.

Full Cell Creosote Process.—This consists of impregnating the wood fibers and cells of ties with 6 to 12 lbs. of creosote oil per cubic foot and timber and piling with 10 lbs. to 20 lbs. of creosote oil per cubic foot, as follows: The wood is first seasoned in the open or steamed in the retorts (generally both) to reduce the moisture and expel the sap; then a vacuum is produced and maintained until the creosote oil is introduced and wood is completely submerged. The pressure is then increased to about 100 to 125 lbs. per sq. in. and maintained until the desired penetration and impregnation is secured, when the creosote oil is drained from the tanks. In some cases a vacuum is produced and maintained at the finish to drain the surplus oil from the exterior of wood to prevent loss by drippage

after the wood has been removed from retorts. The approximate time required is:

	10-lb. Treatment. Hrs.	Mins.
Steaming to 20 lbs. pressure	0	30
Steaming, 20 to 35 lbs. pressure	3	30
Blowing off steam	0	15
Vacuum	0	45
Creosote to 100 lbs. pressure	1	30
Forcing back solution	0	15
Vacuum	.	30
Total cycle	7	15

If the steaming time is reduced 2 hrs., then the total cycle equals 5 hrs. 15 mins.

Rueping Process.—This is often referred to as a partial cell treatment and it is used principally in connection with creosote oil. It consists of forcing compressed air into the pores or cells of wood and at a higher pressure creosote oil without relieving the air pressure and upon relieving the combined pressure the air expands and forces out the surplus oil, leaving wood fibres impregnated. The wood is first air seasoned in the open or steamed in the retorts (sometimes both) to reduce the moisture; with compressed air and by air equalizing reservoirs or pumps the retorts are filled with oil without releasing the air pressure. The oil pressure is thus started at from 80 to 100 lbs. per sq. in. and gradually increased to about 100 to 150 lbs. per sq. in., having the effect of compressing the air in the cells to a smaller volume and permitting about 10 to 12 lbs. of creosote per cubic foot to enter. The pressure is then released and the oil drained from the retorts; then a vacuum is produced, which causes the air within the cells to expand and forces the surplus oil out of the wood, leaving the wood fibres impregnated with from 4 to 6 lbs. of creosote per cubic foot. This process is best adapted for treatment of ties. The approximate time required using equalizing cylinders is:

	Hrs.	Mins.
Air to 80 lbs. pressure	0	30
Transferring oil	0	20
Creosote to 150 lbs. pressure	1	30
Maintaining 150 lbs. pressure	0	15
Forcing back oil	0	20
Vacuum	1	0
Maintaining vacuum	0	15
Draining	0	10
Total cycle	4	20

This time is based on thoroughly air seasoned ties.

Lowry Process.—This is often referred to as a partial cell treatment and it is used in connection with creosote oil. It consists of forcing creosote oil into the wood cells and then drawing out by vacuum the surplus oil, leaving only the wood fibres impregnated. The wood is first air seasoned in the open, then placed in retorts and submerged in creosote. The pressure is then applied by

forcing in additional creosote of 10 to 12 lbs. per cu. ft. at about 180 lbs. pressure so as to saturate the pores and cells, after which the retort is drained and a quick vacuum is produced and maintained from 1½ to 2 hrs., leaving the wood fibres impregnated with from 4 to 6 lbs. of creosote per cubic foot. This process is used principally in the treatment of ties. The approximate time required is:

Ties thoroughly seasoned:	Hrs.	Mins.
Creosote to 180 lbs. pressure	2	00
Draining oil from retort	0	10
Vacuum	2	00
Draining	0	10
Total cycles about	4	20

Card Process.—This process consists of impregnating the wood cells with an emulsion consisting of zinc chloride and creosote oil, as follows: The wood is first air seasoned in the open or steamed in the retorts (generally both) to reduce the moisture and expel the sap. Then a vacuum is produced and maintained for 1 hr., when the retort is filled with the hot emulsion consisting of ½ lb. of dry zinc and from 1½ to 4 lbs. of creosote per cubic foot. The pressure is then applied by forcing in additional emulsion at about 100 to 150 lbs. pressure per square inch, after which the retort is drained and a vacuum produced and maintained for about 30 min. to draw the surplus emulsion from the exterior of the wood to prevent loss by drippage when wood is removed from retort.

It is necessary to keep the emulsion constantly agitated to prevent a separation of the zinc and creosote and to accomplish this a centrifugal pump draws the emulsion from top of retorts and discharges into the bottom of the perforated pipe.

This process is used principally in the treatment of ties. The approximate time required is:

	Hrs.	Mins.
Steaming to 20 lbs. pressure	0	30
Steaming, 20 to 35 lbs. pressure	3	30
Blowing off steam	0	10
Vacuum	1	00
Emulsion to 120 lbs. pressure	1	00
Maintaining 120 lbs. pressure	1	30
Forcing back oil	0	15
Vacuum	0	20
Draining	0	10
Total cycle about	8	25

If the steaming time is reduced 2 hrs., then the cycle equals 6 hrs. 25 mins. If ties are thoroughly seasoned this time can be reduced to 4 hrs. 25 mins.

Cost of Treatment.—The prevailing rates for treating material with these processes depend upon locality, structure of wood, condition of wood; that is, whether it has been air seasoned or requires steaming, residual impregnation and quality to be treated; however, it is safe to assume that the following is an average rate when taking creosote at $0.07 per gal. and zinc chloride at $0.04 per lb.

Process.	Per 7 x 9-in. x 8-ft. tie.	Per 1,000 ft. B. M.
Burnettizing ½ lb. zinc chloride per cu. ft.	$0.17	$4.10
Wellhouse, etc.	0.23	5.50
Card	0.26	6.10
Rueping	0.32	7.60
Lowry	0.32	7.60
Absorption	0.33	7.80
Full cell	0.47	11.15

Cost of Creosoting and Life of Creosoted Timber.—Mr. O. T. Dunn gives the following data: Creosoting costs $15 to $20 per M. Assuming that two 6-ft. cylinders 100 ft. long are used, the capacity of each cylinder is 16,800 ft. B. M. The total plant will cost, say, $80,000. If the timbers are to be impregnated with 20 lbs. of creosote per cu. ft., it will take about 36 hrs. for a run, and the annual capacity of the plant will be nearly 7,000 M. If the interest and depreciation of the plant is assumed at 10% we have $8,000 ÷ 7,000 = $1.14 per M. chargeable to this item. The labor will cost about $3.75 per M. If the oil costs 8 cts. per gal., and 20 lbs. be used per cu. ft., the cost of oil is $15.33 per M. This makes a total of $20.22 per M. If 16 lbs. of oil per cu. ft. are used, the cost of oil is $10.26 per M., thus reducing the total cost by $5. If the plant is not worked to its full capacity, the interest charge per M. becomes greater.

Treated with 20 lbs. of oil per cu. ft., piles in the bridge of the L. & N. R. R., over the mouths of the Pascagoula river, have been in the structure 28 years, and will be good for many years to come. These piles are subject to attacks of the teredo, where uncreosoted piles 1½ ft. in diameter have been cut off by the teredo in a single year.

Beech ties impregnated with 12 lbs. of oil per cu. ft. have lasted 30 years on the Eastern Railway of France.

Mr. Dunn underestimates the "plant charges," for while 10% for interest and depreciation, may be ample, it does not provide for current repairs. No data are available to determine what repairs will amount to, but I should put the item at less than another 10% of the first cost of the plant, excluding land and buildings.

Cost of Creosoting Ties.—Mr. W. H. Knowlton gives the following relative to a tie creosoting plant at Shirley, Ind. Ties are first seasoned 8 to 12 mos., then loaded on "buggies," 55 ties per buggy, running on 30-in. gage track made of 52 lb. rails., and hauled in trains of 15 buggies by an electric motor. There are 200 buggies. Two retorts, 7 ft. diam. × 130 ft. long, receive these trains of ties, hence each retort holds 800 ties. The boilers are rated at 200 hp. The following force is required to work one shift:

1 man at the boilers.
1 headman in retort house.
3 assistants.
15 laborers to handle ties.
1 machinist.

When working at full capacity, two shifts are run. The laborers receive ¾ ct. for each tie handled.

Each tie receives about 2½ gals. of oil, costing 6 cts. per gal. (in 1906), and having a specific gravity of 1.02 to 1.07, averaging 1.05½. A chemist analyzes all oil. The charge for tie treating is 30 cts. per tie, including loading and unloading ties. This plant cost about $75,000. Working only one shift per day, and allowing 5 hrs. for treatment of ties, the two retorts would handle 3,200 ties per day, or about 900,000 per year. Mr. Knowlton does not give the output but states that ties are left in the retort 3½ to 6 hrs.

Cost of a Zinc Chloride Treating Plant.—A zinc chloride tie treating plant was built in 1902 at Carbondale, Ill., for the Ayer & Lord Tie Co. It has 8 cylinders or retorts, 6 ft. diam × 125 ft. long, and the plant capacity is 2,000,000 ties per year, or 250,000 per retort. Each cylinder holds 14 iron cars, each with 30 to 40 ties, or about 500 ties. The buildings are of brick. The main building is 115 × 123 ft., the retort room being 90 × 123 ft. The boiler house contains six tubular boilers 6 × 18 ft. The total cost of the plant is said to have been $175,000, exclusive of yards and tracks. This is equivalent to about $22,000 per retort, including buildings, etc., or about 90 cts. is invested in the plant per tie treated annually. See the section on Railways for other data on zinc chloride plant costs.

Ties Treated With Crude Asphaltic Oil.—On the A. T. & S. F. Ry. some seasoned pine ties were impregnated (in 1902) with California crude oil under a pressure of 150 lbs. per sq. in. Each tie took up 4 to 8 gals. of oil containing 77½% of asphaltum. After 5 years of service they were in first class condition, although untreated ties in the same locality (Southeastern Texas) lasted only 2 to 4 years on account of the heat and moisture.

General Data on the Cost of Framing and Erecting Timber.—A study of the data given in the subsequent pages of this section and in the sections on Buildings and on Railways will show that it seldom needs cost more than $10 per M. to frame and erect almost any kind of a timber structure. In fact $10 per M. is generally used by many contractors as a basis for a rough estimate of the labor cost of any timber work. Nevertheless, it should not be hastily assumed that labor on timberwork does not vary considerably in cost, depending on the character of the work. While it will rarely exceed $10 per M. under good management, it may often be done for as little as $1, and I have, in fact, had men lay plank roads for 50 cts. per M. These very low costs are obviously obtained only where there is no framing, measuring, or sawing, but simply handling and spiking the timber. Even in such simple cases, a little poor management may run the cost up to $2 or $3 per M.

I have made no mention of the rate of wages, for the cost per M. has been almost independent of rates of carpenters' wages. This seems incredible, but I find it to have been so, as a general

rule. Railway companies in America have long paid about $2.50 per 10 hr. day to carpenters in shops and on bridge and building work. Contractors doing similar work often pay carpenters $3.00 to even $3.50 per 8 hr. day, and get the work done at less cost per M. than do the railway companies. The reason is not far to seek. By a process of natural selection the hard working, ambitious carpenters are soon found where higher wages prevail, and their hard work justifies the higher wage. It is the old story. Of course, it is also a fact that the average contractor is a much better manager than the average railway superintendent. That is why the one is a contractor and the other is a superintendent. This is not true of all individuals, but it is true of the classes taken as classes. The workman is usually worthy of his hire.

It does not follow, however, that labor unions may not force up wages without likewise forcing up the output of the workmen. This unfortunate condition—unfortunate, because it is against the best ultimate interests of the workmen themselves—exists in many cities.

Nor does it follow that it is not good economics to use common laborers as much as possible in heavy timber work. The usual mistake in management of timberwork is to let high priced carpenters do loading, carrying, cross-cut sawing, etc., which can be done just as well by common laborers.

Cost of Loading and Hauling Timber.—One man, assisted by the driver of a team, will load 1 M. of 2-in. plank onto a wagon in about 16 mins. These same two men will unload in 12 mins. With wages at 15 cts. per hr. per man, the cost of loading is 8 cts. per M., and unloading is 6 cts. per M. On short hauls, where the team is idle during the loading and unloading, it is necessary to add 7 cts. more per M. for lost team time, if the two horses are worth 15 cts. per hr. This makes a total of 21 cts. per M. for loading and unloading a wagon, including lost team time. Green timber weighs from 3 lbs. to 5 lbs. per ft. B. M., depending upon the kind. Assuming 4 lbs., as an average illustration, we see that 1 M. weighs 2 tons, which is a good load for hard earth roads in first-class condition. If the wages of a team and driver are 30 cts. per hr., and the load is 1 M., and the speed going and coming is 2½ miles per hr., the cost of hauling is nearly 25 cts. per M. per mile measured one way from loading point to unloading point. On muddy earth roads, 1 ton, or ½ M. is often a good load; then the cost of hauling is nearly 50 cts. per M. per mile. I have known earth roads to be so bad that hauling cost 75 cts. per M. per mile. Consult the index under "Hauling" for further data.

The cost of unloading timber from wagons can be entirely eliminated by having a roller 3 ft. long (or two 18 ins. long) at the rear end of the wagon box, and by tilting the wagon box up so that its front end is, say, 2 ft. higher than the rear end. The roller is provided with a ratchet wheel and a dog. Where the dog is tripped the timber rolls out of the wagon by gravity, if long sticks are on the wagon. If sticks are short, other rollers

must be placed in the bottom of the wagon box. All rollers are mounted in bearings, of course.

Sawing, Boring and Adzing.—In heavy timberwork the cost of framing consists mainly in sawing, boring and adzing the sticks. Where a large number of sticks are to be sawed to the same length it generally pays to install a small power saw; but on jobs of moderate size the customary practice is to frame the timbers with a cross-cut saw operated by two men. Using a sharp saw and working rapidly two men can cross-cut a 12 × 12-in. oak stick in 3 mins., but it is generally safer to allow 5 mins. to cover delays.

When a timber is to be notched, or scarfed, a cross-cut saw is used to cut to the bottom of the scarf, then a hatchet or adz is used to cut away the wood roughly, and an adz is used to dress the face. I have seen poor foremen permit workmen to use chisels instead of adzes, thus "making the job last."

A "dap" is a shallow notch cut in a stick.

Mortise and tenon joints are no longer used by those who know how to design economic and durable timber structures. Dowel pins and drift-bolts have largely replaced the old mortise and tenon.

In boring holes for bolts, there are three methods commonly used: (1) Boring by hand with ship augers; (2) boring vertical or inclined holes of moderate depth with hand-power boring machines; and (3) boring with augers operated by compressed air.

A man with a ship auger will bore a 1¾-in. hole in oak, 12 ins. deep in 5 mins, or at the rate of 120 ft. in 10 hrs.

Using a geared boring machine, a man will bore a 1-in. hole 12 ins. deep in 2 mins., by hand, or at the rate of 300 ft. in 10 hrs.

With a pneumatic auger a man will bore a 1-in. hole 3½ ft. deep, in yellow pine chord members of a trestle, in 5 mins. of actual boring time, but 2 mins. more must be added for cleaning the shavings out of the hole, and moving to the next hole, making 7 mins. in all for 3½ ft., or 2 mins. per ft., or at the rate of 300 ft. in 10 hrs.

This is the most economic method of boring where much work is to be done. For cost of operating pneumatic machines, see index under Pneumatic Machines.

Mr. W. E. Smith states that in building an ore dock three pneumatic boring machines were used. The air was supplied by two 9-in. Westinghouse locomotive air pumps, through 1,200 ft. of 1½-in. pipe in one direction of the dock and through 1,000 ft. of 1½-in. pipe in another direction to the framing yard. For air receivers there were one locomotive air reservoir on the dock and one in the framing yard. The air pumps had to work so fast to supply air that a stream of water had to be kept running over their valves to keep them cool. It would require a 20 hp. boiler to supply steam for one of the air pumps working at such a speed. While these air pumps use a good deal of steam, they are very convenient, for they are light, easily moved and can be bolted up

anywhere to a wall or post. The pneumatic borers were run with a pressure of 60 to 90 lbs., and gave great satisfaction.

In the following paragraphs will be found a statement that in boring by hand, each man averaged 80 ft. of hole per day bored through trestle stringers, presumably ⅞ or 1-in. holes, averaging less than 8 ins. deep.

For cost of boring deep holes lengthwise in oak piles, see the index under "Timber Boring."

In boring ¾-in. holes with a ship auger through 12-in. Douglas fir, a man will ordinarily take 3 mins., which is at the rate of 200 ft. in 10 hrs.

Transporting Timber Short Distances.—Never allow carpenters to handle any considerable amount of timber. Provide common laborers for loading, carrying, etc. Rarely should men carry timbers on their shoulders or with lug hooks. Instead, lay run plank over which the timber can be pushed on a dolly, which is a little roller provided with a frame on which the timber is balanced. Often two dollies are used, one at each end of the timber. Even

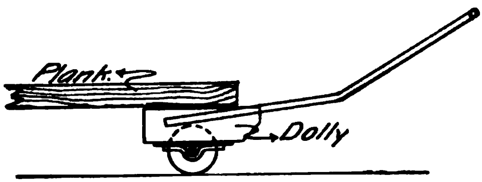


Fig. 1.—Dolly with Handle.

if the timber is light boards, do not permit carrying, but require the boards to be stacked up on dollies.

I have found it advantageous to provide each dolly with a handle, as shown in Fig. 1. Then one man walks ahead pulling the front dolly by its handle, while another man follows at the rear pushing the handle of the rear dolly. The men walk tandem along the run plank until the place of delivery is reached; then, if it is a wooden bridge floor, they swing the rear end of the stick around (still on the dolly) and dump the plank right where it is needed by the carpenters. In loading such plank onto dollies, each man uses a lug hook. A 4 × 12 in. × 20 ft. plank weighed 250 lbs. Two men loaded, hauled, a distance of 60 ft., and delivered one plank every 1⅔ mins., or at the rate of more than 30 M. per 10 hr. day, or about 45 tons of lumber were loaded and transported 60 ft. by two men. A heavier load could readily have been handled on the dollies, but one plank at a time was more economic, since the carpenters were thus relieved of all work except spiking. In that connection I may add that each plank was pinched up tight against the last plank in the floor by a man using a peavey. Another man started each spike with an ordinary hammer, and two men drove the spikes with spike mauls.

Formulas for Quantity of Materials in Trestles.—I have deduced the following formulas from bills of materials of standard trestles on the Northern Pacific Ry.

High frame trestles are built in stories 25 ft. high. The following formulas give the amount of timber in a single-track frame trestle of any given height up to 125 ft.

(1) $M = L\ (220 + 6H)$ for trestles up to 25 ft. high.

(2) $M = L\ (240 + 8H)$ for trestles 25 to 50 ft. high.

(3) $M = L\ (240 + 9H)$ for trestles 50 to 75 ft. high.

(4) $M = L\ (240 + 10H)$ for trestles 75 to 125 ft. high.

M = total ft. B. M.

L = length of trestle in feet.

H = height from ground to 4 ft. below base of rail.

There are 164 ft. B. M. in the timber deck per lin. ft. of bridge, but the above formulas include this deck timber.

There are 70 lbs. of wrought iron and 30 lbs. of cast iron per 1,000 ft. B. M. of deck and half that amount per M. of bents.

Hence

(5) $W = L\ (20 + 0.4H)$ for trestles up to 75 ft. high.

W = weight of iron in pounds, 70% of which is wrought and 30% cast iron.

For closely approximate estimates determine the profile area of an opening that is to be trestled, calculating the area (A) from the ground up to a line 4 ft. below the rail. Divide this area (A) by the length (L) of the trestle, and the quotient is the average height (H). If it is desired to estimate quantities by profile area (A) direct, simply substitute for H in the above equations its value $\frac{A}{L}$.

Equation (1) then becomes

(6) $M = 220\ L + 6A$.

This has the same general form as my formula for the weight of steel in viaducts, which is given in the section on Bridges.

For pile trestles, four piles per bent (bents 16 ft. c to c) and assumed penetration and cut off of pile amounting to 20 ft., we have

$$(7)\quad P = \frac{H + 20}{4} \times L.$$

(8) $M = 185\ L$ for heights up to 15 ft.

(9) $M = 200\ L$ for heights of 15 to 25 ft.

(10) $W = 16\ L$.

P = number of lin. ft. of piles.

H = height of trestle in feet from ground to 4 ft. below rail.

L = length of trestle in feet.

M = ft. B. M.

W = weight of iron in pounds, 40% of which is wrought, 30% cast, and 30% galvanized.

The above formulas (1) to (4) for frame trestles are sufficiently accurate for all but very short trestles, but they give an excess of timber equivalent to the amount in one bent.

The formulas for pile trestles, however, provides for one bent fewer than is usually driven, for it is customary to drive an extra bent at each end to act as a bulkhead, and about 10 planks (4 × 12 ins. × 12 ft.) are placed as a sheeting back of each of these pile bulkheads, to hold back the earth fill. Hence one bent of 4 piles and about 500 ft. B. M. of bulkhead timber should be added to the quantities given by equations (7) and (8) for pile trestles, to be exact.

In the section on Bridges, it will be found that the average height of trestles on the Great Northern and on the Northern Pacific Rys. in Washington was a little less than 20 ft. In which case $H = 16$, and eq. (1) gives us

$M = (220 + 96) = 316$ ft. B. M. per lin. ft.

$W = (20 + 6.4) = 26.4$ lbs. iron.

Hence at $30 per M. for timber in place and 4 cts. per lb. for iron in place, the cost is $10.55 per lin. ft. of trestle.

The following is the bill of lumber in a Northern Pacific pile trestle per 16 ft. length.

	Ft. B. M.
6 stringers, 9 x 18-in. x 16-ft.	1,296
3 packing blocks, 4 x 18-in. x 6-ft.	108
1 spacing block, 4 x 6-in. x 6-ft.	12
14 cross ties, 8 x 8-in. x 12-ft.	896
2 guard rails, 5 x 8-in. x 16-ft.	107
1 cap, 12 x 16-in. x 14-ft.	224
2 lateral braces, 6 x 8-in. x 18-ft.	144
1 cleat, 2 x 8-in. x 10-ft.	14
2 sway braces, 3 x 10-in. x 20-ft.	100
Total	2,901

This is practically the constant for heights (H) up to 15 ft., and is equivalent to 185 ft. B. M. per lin. ft. But above that height is customary to put a horizontal brace midway between the cap and the ground, and use four diagonal sway braces instead of two.

Methods and Cost of Building a Railway Trestle.—A trestle on the Indiana, Illinois & Iowa R. R., near Streator, Ill., was destroyed by a tornado in July, 1903. The right-of-way was quickly cleared by a large gang of trackmen and a new trestle built, using about half of the old timber, all of which had to be framed over again as the bents were made of different heights. The new trestle was 854 ft. long, consisting of 60 bents spaced 14 ft. center to center. Of these bents 43 were double-deck bents, the upper bents being 20½ ft. high, and the lower bents averaging 21 ft. The remaining bents were single-deck. The force averaged 70 bridgemen (carpenters), and 190 trackmen (laborers), and a few teams. This force cleared away the wreckage, and built the new trestle complete in 7 days, not including 1½ days spent in getting men to the site of the work. There were 351,000 ft. B. M. in the new trestle, including ties, and the cost of clearing the site and building the trestle was $11.85 per M. for labor of bridgemen, trackmen and a few teams. The wages were probably about $1.50 per 10-hr. day for trackmen, and $2.50 for bridgemen. The new timber cost $27 per M.

The mortise and tenon is "a back number" on railway trestle work, so the principal tools used were the two-man cross-cut saw, the adz, and the ship auger. The sills were dapped ½-in., and the ends of the posts were framed to 11½ ins. square, ensuring a perfect joint.

The posts were sawed off square, dapped into the cap and drift-bolted, toenailed to the sill with eight ⅝-in. × 10-in. boatspikes in each post.

A peg was driven and numbered to mark the center of each bent, and small stakes were set on each side to mark the location of the plumb legs and batter posts. The ground was then dug to a level surface around each of the four pegs, but no particular care was taken to dig the ground to the same level at all four pegs. Differences in level were made up by using blocks for cribbing under the sills. These blocks were leveled on top by digging earth out from under them where necessary, which did away with adzing or shimming the sill. The blocks under each bent consisted of eight pieces 4 ft. long, two blocks under each post, giving a ground bearing of about 45 sq. ft. per bent.

When a foundation of blocking and the lower sill were in place, the posts and cap for a bent were dragged by teams to the site of the bent and rolled over into position just ahead of the foundation. The sill was rolled over on its side; the plumb posts were butted against the dapped places and toenailed, being centered from the grading pegs. The batter posts were laid near their proper places (but not toenailed), and the cap was drift bolted to all four posts, holes having already been bored in the cap. The cap and sill were held tight to the plumb post with chains and with "right and left screw-pulling jacks." Then the batter posts were crowded in at the bottom and toenailed to the sill. The bent being assembled, one sash brace and two sway braces were spiked across the upper face of the bent as it lay blocked up a few feet above the ground. Four ⅝-in. × 8-in. boat spikes were used at each intersection. The bent was then ready to be raised. A set of double tackle blocks was made fast at each end of the cap and anchored to the cap of the preceding bent which had already been erected and securely braced. The pulling ropes ran through snatch blocks fastened to the sill of this preceding bent, and a team was hitched to each of the two pulling ropes. The team up-ended the bent easily. A subbing rope around the cap, and anchored to any convenient anchorage, prevented the bent from going too far and tipping over. And two temporary struts from the sill of the preceding bent to the sill of the bent that was being raised, prevented the bent from sliding while being raised. When erected, the bent was pinched over so as to be centered on the alinement stake; then plumbed and tied to the preceding bent with sash braces and sway braces. The bents were plumbed by eye, or by lining the posts up with a plumb line string held at arm's length. It was necessary to plumb the bent from both sides. A small gang followed the erectors, putting

on the remaining sash braces, sway braces, tower braces and A-braces.

Teams were used for hoisting the framed timbers for the top series of bents, from the ground to the top of the lower series of bents, where they were assembled and erected practically as above described. To hoist the timbers for the top series of bents, a gin-pole was erected. The gin-pole was 40 ft. high, and consisted of two 3 × 12-in. pieces, 28 ft. long, with another piece spiked between them so as to give a total length of 40 ft. This gin-pole was securely chained to one of the lower bents. At first a series of snatch blocks was used in hoisting the timbers, but this proved too severe on the teams and double blocks were used to multiply the power.

The 8 × 16-in. stringers were run out on the trestle on dollies pushed along run planks. They required but little framing. The ends were cut off so that the joint came over the middle of the cap, and the end of any stringer more than 15½ ins. deep was adzed off to that size, to give an even bearing for the ties. The stringers were then turned over flatwise, and piled three deep (breaking joint) and bored. Then they were lifted apart and 2-in. cast iron packing washers slipped in between, and the bolts were entered and tightened. Sections of stringers 200 to 300 ft. long were bolted together, and then turned over into position. To turn a section over, a stout lever, 10 ft. long, was chained to one end of the section. A set of double blocks and tackle fastened to the end of this lever quickly turned the section over.

In boring the holes through the stringers each man averaged 80 ft. of holes bored per day, that is 40 holes 2 ft. long.

The ties were hoisted from the ground by teams, using gin-poles.

The foregoing description has been prepared from data given by Mr. W. R. Sanborn.

Cost of a Timber Viaduct.—Mr. S. D. Mason gives the following data relating to a high timber viaduct on the N. P. R. R. in the Rocky Mts., near Missoula. The viaduct contained 970 M. of Norway pine, 75% of which was sawed by contract and the rest hewed. The saw mill was put up near the work and all the timber was framed at the mill. The viaduct was 866 ft. long, and 227 ft. high for a distance of about 150 ft. at the center. It consisted of 8 timber towers supporting 7 Howe truss spans of 50 ft. each. On each side of these were M bents supporting straining beams of 30 ft. span each. The timbers were erected by 2 to 4 gangs of 16 men each, a stick at a time. The heaviest stick weighed 1,700 lbs. Both horse and steam power were used for hoisting. The chords of the Howe trusses consisted of two 6 × 12's and one 8 × 12. They were placed and the diagonal braces put in, beginning at the center, the chords being temporarily held by struts and guy lines. It was found impracticable to raise the trusses bodily. Fir angle blocks were used, but their subsequent shrinkage led finally to the building of new Howe trusses. Work was begun Jan. 1, 1882, and completed in 171 days. Laborers and carpenters received

exceedingly high wages, $6 to $7.50 a day, which accounts for the high cost of $37 per M. for framing and erecting. At ordinary wages the labor would have cost about $12 per M. The erecting gangs struck for $10 a day when within 30 ft. of the top, and their wages were raised, but it is not stated how much. The following was the cost of the viaduct:

869 M., at $27	$23,463
101 M., at $16	1,616
87,120 lbs. wrought iron, at 5¾ cts.	5,010
29,940 lbs. cast iron, at 3¼ cts.	973
117,060 lbs. hauled 80 miles, at 2¾ cts.	3,220
Wages of carpenters and laborers	36,336
Salaries of engineers	3,137
Traveling, office and sundry expenses	1,007
Supplies for men	2,860
Blocks, ropes, chains and wrenches	1,300
40 horses, 90 days, at $1	3,600
Hay and oats for same	2,700
Rent of land and land damages	400
Total, at $88.27 per M.	$85,622

Cost of Building a Pile and Timber Approach to a Bridge.—Mr. B. L. Crosby gives the following cost data on the building of a timber trestle approach, 2,960 ft. long, to a double track bridge across the Missouri River, in 1893. The trestle was built by company men. In the trestle there were 1,438 M of yellow pine, 35,220 ft. of piles, and 97,552 lbs. of iron (70 lbs. per M of timber). The cost of unloading, handling and driving piles, including all material and labor (except the cost of the piles themselves) was 13.7 cts. per lin. ft. The cost of unloading, framing and erecting timber, was $7.42 per M.

Cost of Building a Trestle and a Howe Truss Bridge Under Traffic.—An old railway trestle was rebuilt under a traffic averaging one train per hour. The trestle was 300 ft. long and 50 ft. high at the center. The labor of rebuilding this trestle cost $9.90 per M, including taking down and piling up the old trestle timbers. There were 5 men and a working foreman in the gang; 2 men at $2 a day each, 3 men at $1.75, and 1 foreman at $60 a month.

This same gang built a Howe truss railway bridge under traffic at a cost of $28 per M for labor. The cost of framing and placing 30 M of oak ties and guard rails on three bridges was $12 per M, which was a very high cost. For comparative data see the section on Bridges.

Cost of Wagon Road Trestles.—My records show the following costs of building a dozen or more trestles in the state of Washington. The trestles were for highway use, and had a 3-in. plank floor, 16 ft. wide, resting on 7 lines of 4 x 14-in. stringers. Bents were spaced 20 ft. apart, three 10 x 10-in. posts to a bent dapped into and doweled to caps and sills. Sills were of hewed cedar 10 x 15 ins. Caps were 10 x 12 ins. x 18 ft. Sway braces were of 3 x 6-in. stuff spiked to the posts and sill. The supports for the hand rail consisted of 4 x 4-in. posts, 4½ ft. long, spaced 10 ft. apart and bolted to the outer stringers which in turn were drift bolted to the caps. The top or hand rail was of 3 x 4-in. stuff, and the hub rail was 2 x 8 ins.

There was no mortise and tenon work, and the framing was of the simplest type. The bents were framed flat on the ground and upended to place by using blocks and tackle operated by hand power. The flooring and stringers were conveyed to place by dollies. The work was done by subcontractors with few carpenters, and in all cases was handled with excellent judgment and with rapidity.

To frame and erect a trestle 60 ft. long, consisting of two bents and two bank sills, required 4 men only 1½ days. This trestle contained 7 M, of which 5 M were in the floor system (floor and stringers). Three of the gang were laborers, at $1.50, and one was a carpenter, at $2.50, making the daily wages $7 for the gang, so that the cost of building this trestle was only $1.50 per M. This cost was distributed as follows: $4 per M for framing and erecting the bents and the hand railing; 50 cts. per M for laying the stringers and the floor plank. This laying of stringers and plank, where there is nothing to do but to deliver them on dollies, toenail the stringers to the caps, and spike the floor plank to the stringers, can be done very cheaply by common laborers skilled enough to drive nails.

It is not necessary to notch the stringers in order to secure alignment of the tops of the stringers for the plank floor, because in such timberwork perfection of alignment causes a needless waste of labor.

A gang of 3 laborers, on another trestle, laid a floor system containing 15 M of plank and stringers in 1½ days, at a cost of 50 cts. per M.

On another trestle 260 ft. long, it took 4 men 3 days to lay 23 M of stringers and plank in the floor system, at a cost of nearly $1 per M. These men were much slower.

On another piece of road work, where we used round timber for the posts and sills, a gang of 9 men and a team cut and delivered all the necessary timber from the forest, erected and sway braced the bents of three trestles, having a total length of 440 ft. in 12 days. There were 7 framed bents, 12 pile bents (36 piles 20 ft. long, driven 5 ft.), and 6 mud sills in these 3 trestles. The piles were driven with a small horsepower pile driver. Seven of these men were laborers, two were carpenters and bosses. The timber in the bents was not accurately measured to determine the number of board feet, but the approximate cost, including the piles, was less than $16 per M for the bents. The cost of the sawed timber floor system was, of course, much less. I consider this an excellent record, and one not to be equalled except under the best foremanship and with willing, intelligent laborers.

Cost of Trestles, Cross References.—For further data on trestles see particularly the section on Railways. Consult the index under "Timber, Trestles."

Estimated Prices of Howe Truss Bridges.—The following were detailed estimates of cost at standard contract prices for building Howe truss single-track bridges in Washington (in 1906), according

to standard plans of the Northern Pacific Ry. All lengths are lengths over all.

40 Ft. Pony Truss Bridge.

Materials.	
15 M. timber at \$16 + \$2 frt. = \$18	\$ 270
3,500 lbs. wrt. iron at 3 cts. deliv.	105
3,200 lbs. cast iron at 2½ cts.	80
Total materials, \$11.44 per lin. ft.	\$ 455
Labor and Falsework.	
Labor to frame and erect 15 M. at \$15	\$ 225
12 piles (falsework) delivered at \$3	36
12 piles (falsework) driven at \$2	24
4 M. timber (falsework) second hand, at \$6	24
4 M. timber (falsework) erected and taken down, \$10	40
Miscellaneous expense	50
Total labor and falsework, \$10 per lin. ft.	\$ 400
Abutments.	
2 pile abutments at \$250	\$ 500
100 cu. yds. riprap at \$1.50	150
Total abutments, \$16.25 per lin. ft.	\$ 650
Grand total at \$37.50 per lin. ft.	1,505

60 Ft. Pony Truss Bridge.

Materials.	
24 M. at \$18	\$ 432
7,200 lbs. wrt. iron at 3 cts.	216
6,800 lbs. cast iron at 2½ cts.	170
Total materials, \$13.60 per lin. ft.	\$ 818
Labor and Falsework.	
Labor and frame and erect 24 M. at \$15	\$ 360
Falsework, materials and labor	200
Total labor and falsework, \$9.20 per lin. ft.	\$ 560
Abutments.	
2 pile abutments, at \$250	\$ 500
100 cu. yds. riprap at \$1.50	150
Total abutments, \$10.80 per lin. ft.	\$ 650
Grand total, \$37.60 per lin. ft.	2,028

70 Ft. Pony Truss Bridge.

Materials.	
29 M. at \$18	\$ 522
10,300 lbs. wrt. iron at 3 cts.	309
12,000 lbs. cast iron at 2½ cts.	300
Total materials, \$16.16 per lin. ft.	\$1,131
Labor and Falsework.	
Labor to frame and erect 29 M. at \$15	\$ 435
Falsework, materials and labor	225
Total labor and falsework, \$9.33 per lin. ft.	\$ 660
Abutments.	
2 abutments at \$250	\$ 500
100 cu. yds. riprap at \$1.50	150
Total abutments, \$9.30 per lin. ft.	\$ 650
Grand total, \$34.50 per lin. ft.	2,416

100 Ft. Through Bridge.

Materials.

51 M. at $18	$ 918
21,600 lbs. wrt. iron at 3 cts.	648
20,000 lbs. cast iron at 2½ cts.	500
Total materials, $20.66 per lin. ft.	$2,066

Labor and Falsework.

100 lin. ft. erected at $8	$ 800

Abutments.

2 abutments at $300	$ 600
300 cu. yds. riprap at $1.50	450
Total abutments, $10.50 per lin. ft.	$1,050
Grand total, $39.16 per lin. ft.	3,916

120 Ft. Through Bridge.

Materials.

63 M. at $18	$1,184
28,500 lbs. wrt. iron at 3 cts.	855
25,400 lbs. cast iron at 2½ cts.	635
Total materials, $22.30 per lin. ft.	$2,674

Labor and Falsework.

120 lin. ft. erected at $9	$1,080

Abutments.

2 abutments at $300	$ 600
300 cu. yds. at $1.50	450
Total abutments, $8.38 per lin. ft.	$1,050
Grand total, $40 per lin. ft.	4,804

130 Ft. Through Bridge.

Materials.

72 M. at $18	$1,296
34,000 lbs. wrt. iron at 3 cts.	1,020
29,000 lbs. cast iron at 2½ cts.	725
Total materials, $23.40 per lin. ft.	$3,041

Labor and Falsework.

130 lin. ft. erected at $10	$1,300

Abutments.

2 abutments at $300	$ 600
300 cu. yds. riprap at $1.50	450
Total abutments, $8.10 per lin. ft.	$1,050
Grand total, $41.50 per lin. ft.	5,390

150 Ft. Through Bridge.

Materials.

89 M. at $18	$1,502
45,000 lbs. wrt. iron at 3 cts.	1,350
40,000 lbs. cast iron at 2½ cts.	1,000
Total materials, $26.30 per lin. ft.	$3,852

Labor and Falsework.

150 lin. ft. erected at $12	$1,800

Abutments.

2 abutments at $350	$ 700
300 cu. yds. riprap at $1.50	450
Total abutments, $7.70 per lin. ft.	$1,150
Grand total, $47.30 per lin. ft.	7,102

The standard pile abutment contains 14 piles for spans under 80

ft., 16 piles for 80 to 130-ft. spans, and 20 piles for 130 to 160-ft. spans. Obviously the cost of piles will vary with the length. It is customary to assume a 20-ft. penetration. In addition to the piles there were 2,500 to 4,000 ft. B. M. of timber per abutment, and 160 lbs. of iron per M of this timber.

It will be noticed that the cost of Howe truss bridges on pile abutments does not vary greatly per lin. ft. of span, the principal reason being that the abutments constitute so large a part of the cost.

See the section on Bridges and on Railways.

Cost of 160-ft. Span Howe Truss Bridges and Cribs.—In 1894 I designed, and built by contract, two highway bridges over different points on the Noaksack River, Washington. Each bridge had a 16-ft. roadway, a clear span of 160 ft., and a depth of truss of 30 ft. at the center. The bridge was designed to carry 100 lbs. per sq. ft. of roadway. The trusses were a modified type of Howe truss, having upper chords that were not horizontal but sloped up from both end posts to an apex at the center, like a roof truss. This design very materially reduced the amount of iron, which was an important factor. Each chord was made of three parallel timbers, each 6 x 14 ins., bolted together. Panels were 20 ft. long. The floor was of 3-in. cedar plank, for lightness and durability. The rest of the timber was Washington fir. The bridges rested on pile abutments, which were protected by log cribs filled with field-stones. Each bridge contained 40 M of timber, of which 23 M were in the trusses and braces, and 17 M in the floor system.

No piles were driven for falsework, although the river was 4 to 6 ft. deep and swift; but two-post bents were put up just back of each panel point. Bents were made of round timber, and erected by first dropping into the water pairs of long-legged saw horses on each side of the proposed falsework, and laying run planks on the horses for men to walk on. A falsework can thus be built with great rapidity and cheaply, and in spite of the weight coming upon the posts of each bent the settlement in the gravel bottom was very slight, and easily taken up by wedges under the lower chords. There is always danger, however, that a sudden flood will undermine the falsework, and this happened at one of the bridges, causing it to fall during construction.

No upper falsework, except a light staging at each end post and at the center, is needed with this type of truss, provided long sticks of timber can be secured; for with chord sticks 62 ft. long (in a bridge of this size) it is possible to lift, first one end, then the other, of the upper chord sticks and support them upon the light staging at each end, until the diagonal struts are placed.

The trusses must be first framed and bolted together, flatwise on the ground, then unbolted and erected piece by piece. The timbers were pushed out onto the falsework on dollies, and lifted with block and tackle, using a gin-pole where necessary; all this handling being by hand without a hoisting engine. Although the following record of low cost will be hard to equal, it serves to show what can be done with efficient labor under a good bridge foreman.

COST OF 160-FT. SPAN BRIDGE.

Materials.	
40 M. timber, at $7 on cars	$ 280.00
40 M. timber hauled 3 miles, at $2.50	100.00
3,970 lbs. iron rods; 662 lbs. bolts; 769 lbs. gib plates; 326 lbs. drift bolts; total 5,727 lbs., at 3¼ cts.	186.10
14 cast iron angle blocks, 1,316 lbs., at 2¾ cts.	36.20
613 cast iron washers, 613 lbs., at 2½ cts.	15.30
Lag screws, nails, etc.	9.90
Freight on iron	14.50
Total bridge materials delivered	$ 642.00
30 abutment piles, 30 ft. long, at 5 cts. per ft.	45.00
Labor.	
Framing trusses, 6 carpenters 7 days, at $2.50	$ 105.00
Getting out timber for falsework and building driver	40.00
Driving 30 piles, 6 men and 2 teams, 9 days	150.00
Building two log cribs	75.00
Erecting lower falsework, 8 men, 3 days	48.00
Erecting bridge, 4 carpenters and 6 laborers, 7 days	133.00
Laying floor and handrails, 4 carpenters and 4 laborers, 1 day	16.00
Loading, hauling and placing 70 cu. yds. of field-stones in cribs (¾-mile haul)	70.00
Total	$ 637.00
Foreman, at $4 per day	160.00
Grand total labor on bridge and abutments	$ 797.00
Summary	
Bridge materials delivered	$ 642.00
Piles delivered	45.00
Labor	637.00
Foremanship	160.00
Tools, ropes, etc. (one-half charged to each bridge)	100.00
Total cost of one bridge and abutments	$1,584.00

This is less than $10 per lin. ft. of bridge.

Deducting the cost of material and labor on the two pile abutments and their cribs, we have left, $1,200 as the cost of one bridge alone.

If we analyze the labor we find that the wages of the foreman amounted to 20% of the total labor expenditure. This is a high percentage, but one often exceeded on small works of this character where delays due to bad weather or lack of materials, add up very rapidly when the foreman is paid by the month for handling a small gang of men.

It will be seen that the carpenter work of framing the 23 M (exclusive of the floor) cost $4.50 per M, to which should be added about $1.00 per M for foreman. Erecting the bridge (exclusive of 17 M of floor) cost $133 after the falsework was built, or nearly $6 per M (4 erectors being carpenters, at $2.50, and 6 laborers, at $1.50), to which should be added $1.50 for foreman. This makes a total of $10.50 per M for framing and erecting the 23 M in the bridge trusses, to which must be added $2.50 per M for foreman, and $2 more per M for erecting falsework, if we distribute the

labor cost of erecting the falsework over the 23 M. The falsework cost must be estimated for every bridge separately. In this case it was unusually cheap.

The cost of placing the 17 M of flooring on the bridge was less than $1 per M, for there was practically no sawing, adzing or boring to be done—simply running the timber out to place on dollies, and spiking it. This seems an exceedingly low cost, but similar records will be found on other pages. Perhaps no better example will be found in this book to show the necessity of separating plain timber work from framed timberwork in analyzing timberwork costs.

The cost of the pile driving was high per pile not only because the driving was very hard, but because of the small number of piles in each abutment, and because of the cost of moving across the

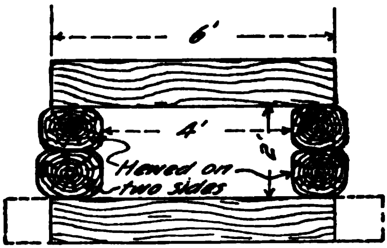


Fig. 2.—Log Culvert.

river and erecting staging for the driver to rest upon at each abutment.

The cribs around the piles were made of hewn timber taken from the forest near by. Each crib averaged 6 ft. high, 10 ft. wide, and 30 ft. long, containing about 6 M of timber. The cost of cutting this timber, hewing and erecting it, was $6 per M, wages of men being $2.50 a day. To this about $1.50 per M. should be added for foreman.

A third crib, built for another bridge abutment, was 10 ft. high, 12 ft. wide, and 35 ft. long, containing about 12 M of hewed timber. It took 5 men 4 days, at $2.50, to cut the timber for and build this crib, which is equivalent to about $4 per M and to this $1 per M should be added for foreman.

For actual cost of Howe truss railway bridges, see the section on Bridges.

Cost of Log Culverts.—In building roads and railways through timbered country, it is generally good practice to build most of the culverts of logs. Log culverts are frequently floored with logs for the full length of the culvert, but they may be built with log sills spaced 4 ft. c. to c., and projecting 1 ft. beyond the walls, as indicated by the dotted lines in Fig. 2.

The ends of a log culvert are stepped up, as in Fig. 3, $l = L - 2D$. Hence the "average length" is $L - D$.

To estimate the lin. ft. of logs in a paved culvert like that in Fig. 2, add 2 ft. to the inside horizontal dimension to get the length of

logs in pavement and in cover, which is 6 ft. in this case. Then double this length and add double the inside height; the sum will be the total lineal feet of 12-in. logs per lin. ft. of "average length" of culvert. In a 2 x 4 culvert (Fig. 2), this gives $(2 \times 6) + (2 \times 2) = 16$ lin. ft. of logs.

There are 0.3 lb. cf ¾-in. drift bolts required per lin. ft. of logs (or 25 lbs. per M when squared timbers are used).

The bidding price is usually about 12 cts. per lin. ft. of logs in place, plus 3 cts. per lin. ft. for hewing two sides, exclusive of the price for the iron. On the Great Northern Railway (517 miles) in

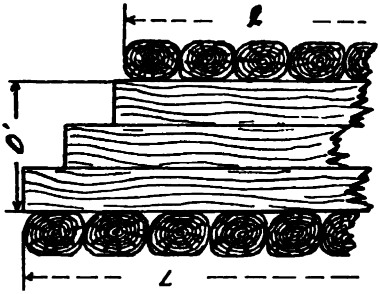


Fig. 3.—Log Culvert.

Washington, the average size log culvert was 3 x 3½ x 43 ft., or 750 lin. ft. of logs per culvert, and I estimated the average contract price in place to be:

	Per. lin. ft. logs.
Logs in place	$0.12
Hewing 1½ sides at 1½ cts. per side	0.02
0.33 lbs. iron drift bolts at 3 cts.	0.01
Excavating 0.04 cu. yds. at 25 cts.	0.01
Total	$0.16

See the sections on Railways and on Bridges.

Materials Required for Timber Box Culverts.—Culverts made of sawed timber are usually designed much lighter than log culverts. A 3 x 4-ft. opening will have wall pieces 8 ins. thick (8 x 12), cover 8 ins. thick (8 x 12), subsills 4 ins. thick (4 x 12) spaced 4 ft., c. to c., and floor 2 ins. thick (2 x 12), making a total of 90 ft. B. M. per lin. ft., and requiring 25 lbs. of drift bolts per M.

Cost of a Wooden Reservoir Roof on Iron Posts.—A reservoir at Pasadena, Cal., was roofed over in 1899, at a remarkably low cost. I am indebted to Mr. T. D. Allin for the following data: The extreme dimensions of the reservoir were 330 x 540 ft., and 166,000 sq. ft. were roofed. The roof was supported by 551 iron posts made of 2-in. water pipe, capped at the bottom and set in cement. On the top of each of these posts a wooden corbel, 6 x 6 ins. x 2½ ft., was fastened by boring a hole 4 ins. deep in the corbel and driving the pipe into the hole. Each post, about 20 ft. long, was up-ended by hand, after the corbel had been driven on, plumbed and tempo-

rarily stay-lathed. Posts were spaced 15¾ and 18 ft. apart. On the posts were laid floor beams made of two 2 x 10-in. plank, overlapped at the ends and spiked together, forming a continuous beam 4 x 10 ins. A gang of 7 men, using movable scaffolding for placing and spiking these floor beams, averaged 1,500 ft. of floor beams per day. On these beams were laid 2 x 8-in. stringers, 16 ft. long. The stringers were overlapped 4 ins. and spiked, and were spaced 6 ft. centers. On the stringers were laid 1 x 12-in. planks, forming the roof. These planks were cut to 12-ft., 18-ft. and 24-ft. lengths, the planks being laid in forms so as to facilitate accurate cutting without individual measurement of each plank. Similar forms were used for cutting the planks used in the floor-beams. The stringers did not require accurate cutting. All the timber was rough, merchantable Oregon pine. The cost of this roof, covering 166,000 sq. ft., was as follows:

260 M. Oregon pine, at $18.70	$4,862
9,373 ft. of 2-in. pipe	987
Nails and spikes	203
Millwork on 551 corbels	27
Cement for footings	6
Engineering	151
Labor, including superintendence	1,004
Total, 166,000 sq. ft., at 4.36 cts.	$7,240

It will be noted that the labor cost was about $4 per M. Mr. Allin informs me that about 75% of the work was done by laborers and 25% by carpenters. The laborers received $1.75 for 9 hrs., and the carpenters, $2.50 for 9 hrs. The work was done during hard times and quite a number of the laborers were really carpenters. Carpenters were used on the erection work and on work around the sides of the structure where neatness was required.

More recently Mr. Allin has completed covering three more reservoirs in a similar manner, the only change in design being the spacing of joists 4 ft. apart instead of 6 ft. He believes that the extra expense is justified because there is less warping of the boards. Wages are now (1905) $4 per 8 hrs. for carpenters, and $2 for laborers, and prices of materials are higher, so that it costs 6 cts. per sq. ft. to cover a reservoir.

For other data on reservoir roofs see the section on Waterworks.

Cost of a Crib Dam.—Mr. J. W. Woermann gives the following cost data for two crib dams across the north and the south channels of Rock River, at the head of Carr's Island, near Milan, Ill., built in 1894. The north dam is 598 ft. long; the south dam, 764 ft. long. The two dams are connected by a levee 1,000 ft. long. The dams are on a rock foundation, and designed to withstand a head of 4½ ft. The dam is a crib of 6 x 8-in. pine timbers, with a rock filling. The main part of the dam is 13½ ft. wide, with an apron 6½ ft. wide, making a total base of 20 ft. A filling of clay and quarry refuse is placed against the cribwork on the up-stream side. The main dam and the apron are covered with 4-in. oak plank, and the up-stream face of the dam with two rows of 2-in. pine sheet-piling. From the crest of the dam to the apron the fall is 3 ft.

An area below the north abutment was stripped for a quarry (June, 1894), and the 800 cu. yds. of stripping, together with 300 cu. yds. of riprap, were used for cofferdams for the north dam. The cofferdams were made as follows: Cribs, 16 ft. square, were built in line, spaced 14 ft. apart. The cribs were built in shallow water by boring holes in the ends of each timber and dropping the timbers over long upright bolts at each corner of the crib. The top of these cribs was sheeted with 4-in. oak plank and weighted down with bags of sand. Timbers, 6 x 8-in., the ends of which were supported by adjacent cribs, were then shoved down into the water. This furnished a cofferdam 130 ft. long, and riprap and quarry stripping dumped against the face of the dam could not be washed away. The 4-in. oak plank was then removed and used in the permanent work. Subsequently the riprap, which was placed on the down-stream side of the cribs, was removed and used in the dam. The quarry stripping was placed on the up-stream side of the cribs. The areas enclosed by cofferdams were 50 to 200 ft. long, and were kept dry with hand pumps. The water in the river was so shallow that wagons were used to deliver all the materials used in both coffer-dams and main dams.

The carpenter work on the south dam was begun Aug. 7 and finished Aug. 22, working 8 hrs. a day, including Sundays. For this dam about 75% of the rock was quarried from the river bed without requiring explosives. During the construction of the coffer-dam for the south dam the force was 14 teams and 50 laborers (for a few rush days there were 130 laborers), and they were engaged from July 24 to Aug. 4. During the erection of the cribwork for the main dam (16 days) the force was 16 carpenters and 50 laborers, about one-third of the laborers assisting the carpenters in carrying timbers, boring, driving bolts and spikes. The number of teams was the same throughout the work.

The total amount of timber in both dams was 330,190 ft. B. M., distributed thus:

	Feet B. M.	
	North dam.	South dam.
Longitudinal timbers (pine)	47,230	73,550
Transverse timbers (pine)	28,350	46,950
Sheet piling timbers (pine)	7,950	14,610
Plank in coping (oak)	33,540	42,840
Plank in apron (oak)	15,870	19,300
Total	132,940	197,250

The cost of the labor of putting this timber into the dams was $5.80 per M.

The rock filling in the north dam is 1,240 cu. yds.; in the south dam, 2,350 cu. yds. The iron used was:

	North dam.	South dam.
Anchor bolts, lbs.	1,010	320
Drift bolts, lbs.	6,050	9,610
Boat spikes, lbs.	4,750	6,050
Wire nails, lbs.	300	400
Total, lbs.	12,110	16,380

The cost of labor on the two dams was:

	North dam.	South dam.
Hauling materials	...	$ 284
Building coffer-dams	$ 730	1,055
Preparing foundation	493	818
Carpenter work on dams	949	965
Quarrying rock, filling cribs and grading above dams	1,966	1,971
Engineering, watching and miscellaneous	362	402
Total	$4,500	$5,495

This makes the total cost of labor $9,995 on the two dams. The total cost was as follows:

Labor	$ 9,995
Rent of land	217
111 M. oak	2,919
218 M. pine	3,087
28,490 lbs. iron	805
Explosives	151
Total	$17,174

Cost of Timber Cribs for Dams, Etc.*—Maj. Graham D. Fitch gives the following:

Timber cribs were built in connection with the building of the lock described on page 989.

The work was done on the Upper White River, Arkansas, by Government forces, common laborers receiving $1.50 per 8-hr. day.

Guide Cribs.—At the head and foot of each lock wall permanent guard or guide cribs were placed. The upper river crib is a solid crib, containing the line of the river wall. It is 150 ft. long and 8 ft. wide on top. The inside face is vertical from the top to 1 ft. below the upper miter sill, below which it is stepped, as is the outer face, so that the width of the base 30 ft. below the top is 20 ft. The lower part of the crib work connects with the lock wall, but above a level 2 ft. below the upper miter sill there is a gap 10 ft. wide between the crib and the lock wall for the passage of drift. The top of the crib is level with the coping.

The lower river crib is 150 ft. long and is similar to the upper crib except that there is no gap between the crib and the lock walls, and that the top of the crib is not level with the coping throughout, that portion farthest down stream being 5 ft. below the coping in elevation.

The land cribs are in line with the lock walls, the upper one being 66 ft. long and the lower one 20 ft. The cribs were built of 10 x 10-in. timbers, framed and drift bolted together, pine being used below pool level and oak above. The cribs are filled with one-man stone, large selected stones being set on edge with their flat faces against the side openings, the top being covered with large, well-shaped stones set level with the timbers.

*Engineering-Contracting, May 6, 1908, p. 283.

The cost of the upper land crib was as follows:

Material.	Unit cost.	Total.	Per M. ft. in crib.
Lumber, pine, 30 M. ft. B. M.	$18.20	$ 546	$80.20
Riprap, 602 cu. yds.	.74	445	14.83
Iron, 2,350 lbs.	.0026	63	2.10
Total materials		$1,054	$35.13
Labor.			
Excavating 45 cu. yds.	$ 1.89	$ 85	$ 2.83
Insp. of timber, 30 M. ft.	.39	12	.40
Riprap, 602 cu. yds.	.008	5	.16
Building and filling, 30 M. ft.	15.42	463	15.43
Backfill, 180 cu. yds.	.525	95	3.16
Total labor		$ 660	$21.98
Grand total (30 M. ft.)		$1,713	$57.10

The labor items in the above work that can be further summarized are as follows:

Work done.	Labor time in days.	Work done per man per day.
Excavating, 45 cu. yds.	46 7/8	.957 cu. yd.
Building and filling, 30 M. ft.	259 6/8	.115 M. ft.
Backfilling, 180 cu. yds.	44 4/8	.404 cu. yd.

The cost of the lower land crib was as follows:

Material.	Unit cost.	Total.	Per M. ft. in crib.
Lumber, pine, 9.3 M. ft.	$18.15	$169	$18.15
Riprap, 145 cu. yds.	.74	107	11.51
Iron, 413 lbs.	.026	11	1.12
Total materials		$287	$30.78
Excavation labor.			
Earth 92, rock 15, 107 cu. yds.	$ 3.26	$242	$26.02
Building and filling, 9.3 M. ft.	...	275	29.65
Insp. of timber, 4 M. ft.	.39	2	.21
Inspection of riprap, 65 cu. yds.	.008	...	....
Total labor		$519	$55.88
Grand total (9.3 M. ft.)		$806	$86.66

The following is the cost of the lower river crib:

Material.	Unit cost.	Total.	Per M. ft. in crib.
Lumber, oak, 14.8 M. ft. B. M.	$16.82	$ 249	$ 5.39
Lumber, pine, 31.3 M. ft. B. M.	14.97	469	10.16
Riprap, 1,014 cu. yds.	.74	714	15.46
Iron and spikes, 5,420 lbs.	...	132	2.86
Fuel	...	21	.45
Total cost materials	...	$1,585	$34.33
Labor.			
Excavating, 980 cu. yds.	$ 0.039	$ 39	$ 0.84
Framing and placing timbers, 46.2 M. ft.	15.60	721	15.60
Filling with riprap, 1,014 cu. yds.	.447	455	9.85
Inspection of lumber, 8 M. ft.	.39	3	.06
Inspection of riprap, 90 cu. yds.	.008	.72	.02
Total labor		$1,219	$26.37
Grand total (46.2 M. ft.)		$2,804	$60.69

The cost of the upper river crib was as follows:

Material.	Unit cost.	Total.	Per M. ft. in crib.
Lumber, oak, 15.6 M. ft. B. M.	$20.12	$ 314	$ 6.60
Lumber, pine, 32 M. ft. B. M.	14.90	477	10.02
Iron and spikes, 1,620 lbs.	.028	46	.93
Riprap, 1,315 cu. yds.	.74	973	20.47
Total cost materials		$1,810	$38.02
Labor.			
Excavation		$ 50	....
Framing and placing timbers, 47.6 M. ft.	$10.32	$ 491	....
Filling with riprap, 1,135 cu. yds.	.31	410	....
Total labor		$ 951	$19.98
Grand total (47.6 M. ft.)		$2,761	$58.00

The average costs of crib materials may be summarized as follows:

	Per cu. yd.
Average cost of riprap, delivered	$ .74
Average cost to place	.436
Average cost in place	1.176

	Per M. ft.
Average cost of crib timber, delivered	$13.82
Average cost to place timber	9.29
Average cost of crib timber in place	23.11

The above costs include field supervision and subsistence, but do not include freight on timber, which is about $1 per M ft.

Crib Dam.—Dam No. 1 was a timber crib structure placed normal to the axis of the river and resting against the buttress of the upper river lock gate, so as to have the whole length of the lock chamber in the lower pool. The dam was 324 ft. long. For the 210 ft. next to the lock it is founded on rock, the remainder of it resting on gravel. The width at the foundation is 48 ft., and the height above the foundation varies between a maximum at one place of 27 ft. (on rock) and a minimum of 19 ft. next to the old abutment. The cribs are of yellow pine except the slope timbers and the face stringers, which are of white oak. All timbers are 10 x 10-in. scantling and are drift bolted together at their intersections. The up-stream face of the dam is vertical to within 2 ft. of the top, whence, to prevent catching drift, it slopes to the crest (a 12 by 12-in. comb stick), having a slope of 1 on 4. The down-stream face sloped from the crest for 8 ft. with a slope of 1 on 4 and was stepped, having two steps each 8 ft. wide and an apron 16 ft. wide, the three vertical intervals being four courses of 40 ins. each. The upper slope was laid closely so as to be water tight; the timbers on the down-stream side of the crest were spaced 1 in. apart. A short section of the dam about 9 ft. in length was in 1900 built inside the lock cofferdam up to the level of the apron. No further work on this dam was done until August, 1902, when work was recommenced by excavating with a dipper dredge. The dam was built in three separate sections, which were partially completed a short distance up-stream, the bottoms being built to suit careful soundings pre-

viously taken, and then towed to position and the building continued. Only every other pen was filled with stone until the last section was in place and weighted. Triple-lap sheet piles, 9 by 12 ins., were driven to rock on the upper side of the dam for 110 ft. out from the abutment where the dam rested on gravel; the remaining portion of the dam, which is on rock, was merely sheeted with double-lap 1¼-in. plank. The lower side of the dam for 120 ft. from the abutment was also sheet piled for the purpose of holding the gravel. The dam was backfilled to within 4 ft. of the eave for about 20 ft. up-stream, partly with gumbo and partly with gravel. Below that portion of the dam on gravel a brush mattress covered with 2 ft. of stone was laid.

The cost of this dam was af follows:

EXCAVATION.

Materials.	
Fuel and oil	$ 96
Labor.	
181 2/8 days	367
Total	$463

FRAMING AND PLACING TIMBERS.

Materials.	Unit cost.	Total.	Per M. ft.
Oak, 132.8 M. ft. B. M.	$19.81	$2,632	$ 5.07
Pine, 387.3 M. ft. B. M.	13.71	5,320	10.23
Iron, 25,297 lbs.	.025	655	1.25
Hauling lumber, 147.4 M. ft. B. M.	1.18	173	.33
Fuel, oil, etc.	...	173	.33
Boat spikes, 12 kegs	8.65	104	.20
Miscellaneous	...	12	.02
Total cost of material, 520.2 M. ft. B. M.	$17.43	$9,069	$17.43
Labor.			
Frame and place, 520.2 M. ft., B. M.	$ 8.84	$ 4,599	$ 8.84
Grand total		$13,668	$26.27

The labor time in days for framing and placing the 520.2 M. ft. B. M. was 2,392⅝, and the average amount framed and placed per man per day was 217 ft.

DRIVING SHEET PILES.

Materials.	Unit cost.	Total.	Per M. ft. Piling.
Oak, 25.2 M. ft.	$19.81	$ 501	$19.81
Boat spikes, 2 kegs	8.50	17	.67
Total materials, 25.2 M. ft.	$20.48	$ 518	$20.48
Labor.			
Driving, 25.2 M. ft.	$22.54	$ 570	$22.54
Grand total		$1,088	$43.02

The total labor time for driving the 25.2 M ft. of sheet piles was 315⅝ days, the work done per man per day being 80 ft. B. M. driven.

FILLING (7,984 CU. YDS.)

Materials.	Unit cost.	Total.	Per cu. yd. Filling.
Riprap, 7,984 cu. yds.	$0.74	$5,908	$0.74
Coal (hauling), 47.1 tons	.50	23	.003
Labor.			
Filling, 7,984 cu. yds.	.425	3,508	.428
Grand total		$9,439	$1.18

The total labor time for filling was 1,999 days, the average work done per man per day being 4 cu. yds. of filling.

PUDDLING (8,640 CU. YDS.).

Material.	Unit cost.	Total.	Per cu. yd. Puddling.
Fuel and oil	...	$ 148	$0.017
Riprap, 60 cu. yds.	$0.74	44	.005
Labor.			
Digging and placing 8,640 cu. yds.	.277	$2,395	.277
Grand total		$2,587	$0.299
REPUDDLING (1904).			
Labor, 4,550 cu. yds.	$0.336	$1,529	$0.336
Cost both years, 13,190 cu. yds.		4,116	.312

	Total.	Per lin. ft.
Dam, 324 lin. ft.	$28,774	$88.81
		Per cu yd.
Dam, filling 7,984 cu. yds.	.....	$3.60

SUMMARY OF DAM NO. 1.

	Total.	Unit cost.
Excavation	$ 463	.....
Framing and placing timber, 520.2 M. ft.	13,668	$26.27
Sheet piles, 25.2 M. ft.	1,088	43.02
Filling, 7,984 cu. yds.	9,439	1.18
Puddling, 8,640 cu. yds.	2,587	.299
Repuddling (1904), 4,550 cu. yds.	1,529	.336
Protecting apron and end of dam after flanking of abutment (1903)	1,212	.....
Changing shape of old dam from step to slope (324 lin. ft.)	6,177	19.06

The cost of Dam No. 2 is given in equal detail in *Engineering-Contracting*, but it will suffice here to say that each man framed and placed 250 ft. B. M. per day, at a cost of $7.62 per M, there being 600 M all told.

Foundation Crib.—The crib was T shaped in plan, following the general outline of the dam abutment. The length of the river face was 136 ft., its width was 12 ft. at the up-stream end and 16 ft. at the down-stream end, and 24 ft. near the middle for a distance of 37 ft., beginning 46 ft. from the up-stream end. The portion of the crib underlying the stem of the abutment was 20 ft. wide and 60 ft. long from face to end; it entered the bank 36 ft. The crib, which was constructed of 10 by 10-in. squared timbers, was built afloat and with interior pens varying in size from 5 to 10 ft. to 10 by 12 ft. After having been settled in place it was filled with "one man" stone up to 2 ft. below extreme low water (6 ft. below water level at the time), the filling averaging 11 ft. in depth. Before this filling began, however, the distributing boxes for the grout were placed. These consisted of open-ended square boxes (8 by 8

ins. inside) of 2-in. plank perforated with 1½-in. holes spaced zigzag 1 ft. apart down the sides. They were long enough to reach just above a loosely laid floor on the top timbers and were set about 10 ft. apart throughout the crib. The cost of these boxes is given under grouting. After the grout boxes had been placed and the crib filled with rubble 9-in. triple-lap sheet piling was driven with a steam hammer along the outside of the crib from a point opposite the downstream edge of the apron to the up-stream end of the crib, and thence around the end and along the up-stream face of the stem. The other faces of the crib were sheeted with double-lap 1-in. plank driven by hand mauls. The sheet piling was also for the purpose of preventing leakage under the abutments, otherwise the double sheeting of 1-in. plank would have answered throughout. The sheet piling and plank sheeting were well spiked to the top timbers of the crib. Gravel and earth were then deposited around the crib up to the water level for a double purpose: First, to prevent the grout from forcing its way through the sheeting, and second to serve as a cofferdam when the time came to pump out the crib.

The cost of this foundation crib was as follows:

FOUNDATION CRIB.

Material.	Total.	Per M. ft. of crib.
Lumber, pine, 65.3 M. ft. B. M. at $11.36	$ 742	$11.36
Lumber, hauled, 50.3 M. ft. B. M. at $1.25	63	.96
Iron, 5,123 lbs., at $0.023	119	1.82
Miscellaneous materials	100	1.53
Total cost of materials	$1,024	$15.67
Labor.		
Framing and placing, 65.3 ft., 981 2/8 days	$1,859	$28.47
Grand total	$2,834	$44.14

The average work done per man per day was 66.6 ft. B. M. of timber framed and placed.

SHEET PILES AND SHEETING.

Materials.	Total.	Per M. ft. in place.
Lumber, oak, 18.8 M. ft. B. M., at $15.79	$ 299	$10.40
Lumber, pine, 9.9 M. ft. B. M. at $13.99	139	4.82
Lumber, hauled, 9.9 M. ft. B. M., at $1.25	12	.86
Spikes, 800 lbs., at $0.031	25	.42
Total cost of materials	$ 475	$16.50
Labor.		
Driving, 28.7 M. ft., 334 days	$ 730	$25.43
Grand total	$1,205	$41.93

FILLING WITH RIPRAP.

Material.	Total.	Per cu. yd.
Riprap, 876 cu. yds., at $0.74	$ 648	$ 0.74
Labor.		
Filling and placing, 118 days	$ 235	$ .27
Inspection of riprap, 10 days	18	.02
Grand total, 876 cu. yds. riprap	$ 901	$ 1.03

The average work done per man per day was 6.84 cu. yds. of rip-rap placed.

Cost of a Coffer-dam and Aqueduct.—In 1840, on the Erie Canal, when skilled laborers were paid $1 per day of 11 hrs. worked (and stonecutters received $2.25 a day—carpenters' wages not stated), a cofferdam (built by contract) containing 157,500 ft. B. M. of timber and plank was built with 830 days of skilled labor and a few carpenters. This is equivalent to 190 ft. B. M. per man per day. If wages had been $2 per day, this would have meant a cost of $10.50 per M.

In building (by contract) an aqueduct trunk or flume, supported by masonry arches, the timber gang consisted of 2 carpenters to every 1 skilled laborer. There were put in 892,400 ft. B. M. of timber, of which 260,300 ft. B. M. were framed. This required 3,153 days of carpenters and laborers. The average day's work for each man was:

	Ft. B. M.
Framing	648
Putting in the work	324

If wages had averaged $2.60 per day (2 carpenters to 1 laborer) this would have meant a cost of $4 per M for framing and $8 per M for putting in the work, or a total of $12.

Cost of Four Caissons.—Mr. B. L. Crosby gives the following on the construction of four piers for a double-track bridge across the Missouri River, for the St. Louis extension of the St. L., K. & N. W. R. R. The foundation work was done by company labor. The masonry piers were founded on pneumatic caissons, each 30 x 70 ft. outside measure, excepting one which was 24 x 60 ft. The caissons were 16 ft. high, including the iron cutting edge, and surmounted with a timber cribwork. This cribwork was 24 ft., 45 ft., 58 ft. and 64 ft. high, respectively, on the four piers. All the caissons, except one, were built on launching ways on the north side of the river, just above the bridge line. These launching ways were constructed by driving piles, which were capped by 12 x 12-in. timbers running up and down stream, and then the 12 x 12-in. way timbers were drift-bolted to the caps. The ways had a slope of 3 ins. to the foot toward the river, and extended far enough out to allow the caisson to float before being clear of the timbers. Piles were cut off under water with a circular saw, and the drift-bolts, which had been started into the caps before they were sunk, were driven by a ramrod working through a gas-pipe over the drift-bolt. To remove a sand-bar at the site of one of the piers, a steamboat was anchored to piles over the pier site, and by the revolution of its paddle wheels washed out a hole 7 to 10 ft. deep. Barges were placed each side of the caisson, and heavy timbers bolted across the caisson, and extending out over the barges. The caisson was towed to its site, and when it struck a sand-bar, air was pumped into the caisson to raise it so as to clear the bar. In sinking the caisson a Morrison sand-pump and a Morrison clay-hoist were used. The greatest depth reached below low water was 101 ft., and laborers in the caisson received $3.50 a day of 2 or 3 hrs. (working 1-hr. shifts) at this

great depth. The pneumatic plant used in sinking consisted of two No. 4 Clayton duplex compressors, having steam and air cylinders, each 14-in., with a 15-in. stroke; a Worthington duplex pump, 18½ x 10¼ x 10 ins., and a small dynamo and engine. This plant was set up on the steamboat whose boilers furnished the power. There was also a duplicate plant, which was used part of the time, supported on a pile platform. There were several hoisting engines, a pile driver boat provided with a derrick for handling timbers in building up the cribwork on the caissons. The concrete used to fill the cribwork was 1:2:4 Louisville cement, and 1:3:6 Portland cement.

In these four caissons and cribs there were 1,609 M of yellow pine. The cost of framing and building the caissons was $21.93 per M. This includes cost of launching ways, and of material and labor of all kinds; except the cost of the timber itself. It also includes all handling and towing. Carpenters were paid $2.50 and laborers $1.75 per day.

There were placed in these caissons 13,285 cu. yds. of concrete requiring 16,035 bbls. of Louisville cement and 4,759 bbls. of Portland cement. The cost of this concrete (broken stone was used) was $5.36 per cu. yd.

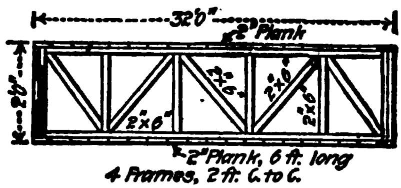


Fig. 4.—A Small Scow.

The average cost of caisson and concrete filling, including cutting edges, shafting, etc., was 34.2 cts. per cu. ft.; the average cost of sinking 9.17 cts. per cu. ft., this average being materially increased due to some rock excavation on one pier where the average cost of caisson sinking was 12.33 cts. per cu. ft. The average cost of caissons was $178 per ft. sunk, ranging from $116 per ft. on one to $259 per ft. on the one where rock was encountered. Work on the first caisson was begun July 30, 1892, and it was launched Aug. 20. It reached bed rock Jan. 2, 1893, at a depth of 89 ft. below low water. The first engine passed over the completed bridge Dec. 27, 1893.

For much more detailed costs of caisson work see data in the section on Bridges.

Cost of Two Small Scows.—For use in river work, two small scows were built as shown in Fig. 4. Each scow was 2 ft. deep, 6 ft. wide, and 32 ft. long. It consisted of four parallel frames made by spiking 2 x 6-in. hemlock to form rough trusses. These frames were 2 ft. apart, and to them rough hemlock sheeting plank was spiked,

making deck bottom, sides and ends of a closed box. All the joints, except the deck, were calked with oakum and tarred. Thus very cheap and watertight scows were made. They were strong enough to be used for a floating pile driver, by bolting the two scows side by side; but they were not quite large enough for this purpose and the leaders of the pile driver had to held with guy ropes, which was a great nuisance. Nevertheless, this rough and light construction proved good enough in every other respect for river work where no logs or other heavy objects could batter the scows. The cost of these two scows was as follows:

3 M. rough hemlock, at $11	$33.00
15 lbs. oakum, and necessary pitch	1.50
1 keg nails	2.00
12 days' labor, at $2	24.00
Total for two scows	$60.50

This is equivalent to $30 each for the scows. One carpenter, at $2.50, assisted by one laborer, at $1.50, did the work, which cost $8 per M. During the winter the scows were hauled out of the water, and next spring re-calked with 8 lbs. of oakum, requiring the labor of one man for 14 hrs. Each scow was readily loaded on a wagon for transportation.

Cost of a Semi-Circular Flume.—Mr. William H. Hall is authority for the following relating to the work on the Santa Ana Canal of the Bear Valley Irrigation Co., in San Bernardino County, California, in 1894. Wooden stave pipe and a semi-circular stave flume, invented by Mr. Hall, were largely used, and cost data are given. The flume is 5½ ft. in diameter, semi-circular, made of dressed redwood staves 1¾ ins. thick held by binding rods or hoops (2 ft. 8 ins. apart) passing through 4 x 4-in. wooden cross-yokes. The flume rests on sills or bolsters (10 ft. apart) cut to fit its curved bottom, and these sills are supported on concrete blocks or on wooden trestles according to the locality. A gang of 10 laborers and 5 carpenters and a foreman built the flume. Not a nail was used in its construction. Wages were high, being $2 a day for laborers, $3 a day for carpenters, and $4 a day for team and driver. The cost of erecting the flume, exclusive of trestle work, was $5.75 per M, but this does not include shop work, delivery and calking. The cost of delivering the lumber in wagons was $2.50 per M and subdelivering it on dollies was $2.50 per M more, as the work was in a rough country; hauling costing 37½ cts. per ton mile by contract. The cost of making the sills, and yokes, and dipping all the lumber in coal tar, and calking after erection, came to $3.25 per M, including all timber in the flume, exclusive of trestles. Hence the total labor cost, including delivery and subdelivery, was $14 per M. The lumber was bought for $28 per M.

The cost of framing and erecting timber trestles to support this flume was $13 per M, the rough pine itself costing $19 per M; the cost of delivering was presumably $5 per M. The work was half over before the men became trained to their work, and at no time were they very active or efficient.

The total amount of dressed redwood for the flume staves was 312 M, which required 214,000 lbs. of wrought and cast iron for bands, bolts, etc., or about 700 lbs. per 1,000 ft. B. M. This iron cost 5¼ cts. per lb. At these high prices the cost of the finished flume was about $5 per lin. ft., of which $2.50 was for the flume alone and $2.50 for the trestle supporting it.

Cost of a Wood Flume, Klamath Irrigation Project.*—The flume is 4,303 ft. long, and has an inside width of 11 ft. and inside height of 5½ ft.; it rests on concrete piers with rubble-stone foundations, and is built of red fir lumber. Of Class 1 lumber, for the framework of the flume, 442,000 ft. B. M. were purchased at $15.50 per thousand, delivered. Measurement after construction, however, showed only 438,000 ft. B. M. in place, and thus indicated a waste of 4,000 ft. B. M., or a little less than 1%. Of Class 2 lumber, for lining the flume, 60,000 ft. B. M. were purchased at $30.50 per thousand, delivered, and 227,000 ft. B. M. at $19 per thousand, making a total purchase of 287,000 ft. B. M. Measurement after construction showed 284,200 ft. B. M. in place, thus indicating a waste of 2,800 ft. B. M., or about 1%.

The concrete piers and stone foundations were built by force account. The piers, 1,091 in number, are 18 ins. high, 24 ins. square at the base, and 12 ins. square at the top, and rest on rubble foundations 3 ft. square.

The total costs on which the tabulated unit costs are based are $21,000 for the flume proper and $6,995.88 for the foundations; in addition, however, there were costs, not distributed in the unit costs, of $174.96 for a spillway and $347.54 for miscellaneous expenditures, making a total cost for the whole structure of $28,518.38, or $6.64 per lin. ft. of flume.

	—Per M ft. B. M.—		Flume
Labor:	Class 1.	Class 2.	per lin ft.
Superintendence	$ 0.46	$ 1.02	$0.11
Carpenter work	5.97	4.83	.93
Distributing timbers	.63	.63	.11
Miscellaneous	.21	.17	.03
Material:			
Lumber delivered	15.64	21.60	3.02
Bolts and washers	.36	.....	.04
Nails and spikes	.94	.94	.16
Engineering and inspection	2.91	2.91	.50
Totals for flume proper	$27.12	$32.10	$4.90
Piers and foundations			1.62
			$6.52

Cost of Lock Gates.†—Maj. Graham D. Fitch gives the following: The gates for the lock described on page 570 are of the standard form, namely, mitering gates of the girder type with straight back and front. They are horizontally framed and without quoin or miter posts, the main timbers extending from edge to edge of the

**Engineering-Contracting,* May 26, 1909.

†*Engineering-Contracting,* May 6, 1908, p. 281.

gate and the ends, which are built up solid with filling blocks, being shaped to fit the hollow quoin and miter, respectively, thus avoiding the weakness of beams jointed into vertical heel and toe posts. The rise was taken as 1/6 of the span, which is equivalent to a miter angle of 18 degrees 26 minutes.

The gates are of white oak, 20 ins. thick throughout, each arm consisting of a built-up beam composed of two 10 by 10-in. timbers bolted together with 1-in. bolts and extending in one length from toe to heel. The tops of the gates are flush with the tops of the lock walls, so that the lock can be used until the walls are submerged. The lower gates, which are 29 ft. 5 ins. in height, are built solid for 10 ft. from the bottom. For the upper gates these figures become 15 ft. 5 ins. and 20 ins., respectively. By making the lower portion of a gate solid, the gate may be made thinner, thus reducing under pressure. The upper portions of the gates are paneled; the arms are all made of the same scantling as below, but are spaced inversely as the maximum loads; the arms are separated by five blocks (including the two at the heel and toe), and the intervals are closed with a sheathing of 2-in. oak plank made watertight by calking. The beams are held together by seven pairs of long 1⅛-in. bolts running vertically through the center lines of the main timbers as well as through the filling blocks in the upper part of the gate. The weight of the gate is taken up by two diagonal tie straps of 3½ by ¾-in. wrought-iron eyebars provided with turnbuckles; one end of each eyebar passes over a pin in the journal strap and the other over a similar pin held in place near the lower end of the toe by a stirrup strap and a nose strap. The bottom beam is fitted at the quoin with a cast-iron heel piece which rests on a forged steel pivot shrunk into a cast-iron pivot plate having sufficient bearing. This bedplate is bolted to the concrete. The top gudgeon is a 3-in. steel pin supported at both ends by journal castings, between which the collar works. In order that the leaf may, in opening and closing, swing clear of the quoin without friction, the rotation axis of the pivot and gudgeon is on the up-stream side of the center of figure of the hollow quoin when the leaf is closed, the eccentricity being 1¾ ins. The up-stream half of the toe is rounded off so that the surface of contact when the gates are mitered shall fall upon the down-stream timbers of the built-up beams. Thus the compression due to the end reactions is thrown on the down-stream timbers where it will relieve the tension from the direct loading, and is removed entirely from the up-stream timbers to avoid increasing the compression from the direct loading.

The anchorage for the gates consists of four wrought-iron bars with cast-iron washers or anchor plates embedded in the concrete and connected in pairs at their exposed ends to two heavy castings. The anchorage connections fit in a recess below the coping and are covered with a cast-iron plate.

The method of building and placing the lock gates was as follows:

A small hand-power derrick was erected on a level spot so as to command the ways, which were built of heavy timbers laid perfectly level about 2½ ft. from the ground and close enough together to support without deflection the weight of an entire gate. On each side of the derrick were placed two sets of ways, between which ran a track for carrying the timbers. The gate timbers were delivered as needed to the derrick and placed on the ways, the built-up beams framed and bolted, and the heel and toe worked to pattern. The arms and blocks were then juxtaposed in position so as to get the alignment of the long bolts and then separated for the holes to be bored. This was a tedious procedure, as no matter how carefully the measurements for the holes were made it was found impossible to bore all of them in the different pieces so as to avoid slight errors of alignment; hence burning the holes out with long rods of hot iron had to be resorted to. The gate was then assembled, the bolts inserted and tightened, the irons fitted on, the heel and toe worked to pattern, and each arm and block numbered to avoid any displacement later. The gates were then taken apart and transported to the lock pit to be erected piece by piece, for which a land derrick was used. As each beam was put into position its top was given a heavy coat of white lead, and the position of its bolt holes tested by thrusting down an iron rod. After the gate had been thus built up to the required height, the long perpendicular bolts were raised by the derrick and put into place, the various irons fitted, the anchor bars and tie straps tightened, and the gate swung. The gates were then given two coats of red lead.

The gates are operated by hand power. The maneuvering gear consists of a spar, to each end of which is fastened one end of a chain; the bight of this chain is led through a chain guide consisting of two sheaves to a chain capstan worked by a crank. The gate is opened or closed according as the chain is pulled in one direction or the other.

As wooden lock gates subject to varying lifts, unless made too heavy at low water, are too buoyant at high water, it is necessary at the approach of floods to ballast them, which was done by filling the panels with large stones.

The miter sills, which provide an elastic cushion for the bottom of the gates, consist of 12 by 12-in. timbers well bolted to the miter wall, as they may sometimes be subjected to a lifting pressure from the gates, and when once started the upward water pressure is of course added. The miter sills are 2 ins. higher than the miter walls so as to act as a guard for the masonry. The miter sills are 1 ft. below normal 4 ft. depth, so as to permit the pool level to be reduced without affecting navigation. The sills, like the gates, are of white oak and were set when the concrete was placed in the miter walls. The gates do not, when shut, extend over the sill, as is sometimes the case, for a difficult joint then becomes necessary. In this instance the gates lap the sill by 5 ins., the under pressure being counterbalanced by the weight of the gates.

The cost of the gates and sills was as follows:

Material:	Unit cost	Total
Lumber, oak, 35.7 M ft. B. M.	$41.37	$1,477
Iron, wrought, 342 lbs.	.05	17
Iron, wrought, 16,243 lbs.	.06	975
Iron, wrought common, 153 lbs.	.023	4
Iron, cast, 600 lbs.	.046	28
Iron, cast, 5,354 lbs.	.045	241
Steel, 615 lbs.	.065	40
Journal castings and patterns	....	22
Total materials		$2,803
Labor:		
Inspection of lumber, 33.9 M ft.	$ 0.3897	$ 13
Hauling miscellaneous material	....	15
Framing, 35.7 M ft.	43.28	1,545
Setting gates, 4	76.54	306
Care, repair and adjusting since 1901, 4.	....	887
Total cost of labor		$2,766
Grand total		$5,569

The total labor time in days for framing was 684 4/8 and the work done per man per day was 52.1 ft.; the total labor time for setting the four gates was 149⅛ days.

Cost of a Railway Box Car.—Mr. E. C. Spalding is authority for the following data on small box cars built in 1883. The car was probably designed to carry about 30,000 lbs., for its own weight must have been about 23,000 lbs.

Material in Body:	
4,000 ft. B. M., at $20	$ 80.00
700 lbs. wrought iron, at $0.05	35.00
600 lbs. cast iron, at $0.03	18.00
Nails	5.20
46 lbs. draw-springs, at $0.09	4.14
Tin for roof	12.60
Paint	3.30
Total material in body	$158.24
Labor on Body:	
20 days carpenter, at $2.25	$ 45.00
2 days tinner on roof, at $2.00	4.00
1½ days painter, at $2.00	3.00
Total labor on body	$ 52.00
Material in Trucks:	
4,200 lbs. wheels; 1,400 lbs. axles	$160.00
64 lbs. brasses, at $0.22	14.08
184 lbs. springs, at $0.09	16.56
490 ft. B. M., at $20	9.80
1,000 lbs. wrought iron, at $0.05	50.00
1,300 lbs. cast iron, $0.03	39.00
Paint	0.80
Total materials in trucks	$290.24
Labor on Trucks:	
2¼ days carpenter, at $2.25	$ 5.63
¼ day painter, at $2.00	0.50
Total	$ 6.13
Grand total	$506.61

It will be noted that the cost of the labor on the box of the car was $45 for 4,000 ft. B. M., or $11.25 per M. The labor cost on the 490 ft. B. M. in the trucks was practically the same rate.

By reference to data in the section on Buildings, it will be found that the labor costs of frame buildings is about the same as above given for this box car.

Cost of Making Bodies for Dump Cars.—Some bodies for bottom-dumping cars were made to be mounted on ordinary hand-car trucks, and were used in filling a trestle. The car bodies were made hopper shape, the sides being 4 ft. apart; the ends were 6½ ft. apart at the top and sloping toward the center until they were 4 ft. apart at the bottom. The height of the body was 20 ins., thus giving a struck-measure capacity of 33 cu. ft. Two doors, forming the bottom of the car, were hinged to the two ends of the car body with three 14-in. strap hinges to each door. These doors were each 18 ins. wide and 4 ft. long, and were closed by means of hoisting chains (¼-in. iron) passing around a 2½-in. gas pipe winch which spanned the car from side to side. This 2½-in. gas pipe was stiffened by a 2¼-in. pipe slipped inside. It required 150 ft. B. M. of plank to make each car, and a carpenter (25 cts. per hr.) with a helper (15 cts. per hr.) averaged one car in 7 hrs., which is at the rate of $10 per M.

Cost of Making Tool Boxes.—A carpenter made two tool boxes of 1-in. matched pine boards in 10 hrs. Each box contained 130 ft. B. M., so that the labor cost was a little less than $10 per M, wages being 25 cts. per hr.

Cost of Plank Roads.—Very often the contractor would be enabled to haul much larger loads in wagons if he were to build plank roads up certain short steep ascents, or up out of the pit. The planks need not be spiked to the stringers. Plank for such roads should be 8 ft. long and 3 ins. thick. Contrary to general opinion cedar makes an excellent plank road, for its surface soon becomes a thin mat of wood fibers and dirt that protect the body of the plank. Either three lines of 4 x 6-in. or two lines of 3 x 12-in. cedar stringers should be bedded in the ground and the plank laid upon them without spiking.

In the State of Washington I found the cost of building the very best of these plank roads to be as follows: Three skilled laborers bedding three lines of 4 x 6-in. stringers in clay, laying and spiking 3-in. plank, averaged 15,000 ft. B. M. per 10-hr. day. At $2.50 per day per man, the cost would be 0.50 per M. In sand these men averaged 18,000 ft. B. M. per day. They were hustling, as they received 50 cts. per 1,000 ft. B. M. for laying this road, plank being delivered alongside.

Over such a road a team can pull as much as on the very best asphalt pavement. The "trick" about building a good plank road is to bed the stringers, not leaving them on top of the ground. The road then is firm and great loads can be hauled over it, so long as it is kept in good condition.

Since in temporary roads the spiking may be omitted, and as a

matter of fact it should be omitted even on permanent roads, we see that the plank may be used over and over again for different jobs; but if the road is worth laying at all it is worth laying well in the first place.

Plank road work lends itself admirably to payment by the piece rate or by the bonus system.

Piles.—Piles are sold by lumber dealers at 5 to 15 cents per lin. ft. of pile for all ordinary lengths, but very long piles bring high prices per lin. ft. Specifications usually provide a contract price per lin. ft. for "piles delivered" on the work ready to drive; and another price per lin. ft. for "piles driven." The length of the "pile driven" is the full length of the pile left in the work after cutting off the broomed head, although occasionally it is specified to be the length of the pile underground. Hence care should be taken to make clear what is meant by the expressed "per foot of pile driven."

The actual cost of driving a pile should be recorded in dollars and cents per pile, as well as in cents per lin. ft. of pile driven; for costs vary less per pile than per lin. ft. This is evident when we consider that where the driving is easy a very long pile is driven in no longer time than is required for a short pile where driving is hard.

I prefer to specify payment for "piles delivered" by the lineal foot, and for "piles driven," by the pile.

Pile Drivers.—There are three types of pile drivers: (1) Free fall; (2) friction-clutch; and (3) steam-hammer. In the free-fall driver, the hammer is detached from the hoisting rope and allowed to fall freely upon the pile. In the friction-clutch driver, the hammer remains always attached to the hoisting rope, and, by means of a friction clutch on the hoisting engine, the drum is thrown into gear or out of gear at will. When the clutch is thrown out of gear, the hammer falls, dragging the hoisting rope after it. The Nasmyth steam-hammer is raised by steam acting direct upon a piston attached to the hammer. The hammer is raised about 3½ ft., and allowed to fall by gravity.

A steam-hammer strikes about 60 blows per minute. A friction-clutch hammer strikes about 18 blows per minute when the hammer falls 12 ft.; and 25 blows per minute when the hammer falls only 5 ft. A free-fall hammer strikes about 7 blows per minute when the fall is 20 ft. and a hoisting engine is used.

The free-fall hammer is much used where horses do the hoisting instead of an engine. In either case a lug on top of the hammer is gripped by a pair of "tongs," which are tripped at the desired height, allowing the hammer to fall. The "tongs" descend slowly by gravity helped perhaps by the man who has tripped them, and they automatically grip the hammer again. The "tongs" are also called "scissors" or "nippers."

The two upright timbers that guide the hammer are called "leads," or "leaders," or "gins," or "ways." A common weight of hammer for a free-fall or a friction-clutch machine is 2,000 to 3,000 lbs.

An "overhang driver" is a driver provided with leads that project

8 to 20 ft. beyond the base of support of the driver. The horizontal beams that support the leads of an overhang driver are trussed; and the weight of the engine on the rear of the trussed beams counterbalances the weight of the leads and the hammer on the front. A cheap driver of this type can readily be made for driving the bents of a pile trestle across a river, or other body of water, where a scow is not available for mounting the driver upon. The author has built such a driver with a 20-ft. overhang for driving falsework pile bents across a river.

A "railway pile driver" is a heavy driver of the "overhang" type, mounted on a railway flat car. Sometimes these drivers are made self-propelling; but frequently a locomotive is used in handling the driver. The leads are so made that they can be lowered when passing under overhead bridges, etc. In working with an overhang driver, there is always considerable delay, for as soon as the 3 or 4 piles for a bent have been driven, they must be sawed off and capped with a 12 x 12-in. stick drift-bolted to the piles, before the beams or stringers can be laid to support the driver when it moves forward.

A "scow driver" will drive more piles per day than a "railway driver," because this delay in sawing off and capping each bent does not occur. Moreover, the piles are floated alongside the driver ready for instant use. The scow itself is quickly shifted by means of ropes from suitable anchorages to the winch-heads of the engine.

Excepting on railway work, land drivers (as distinguished from scow drivers) are seldom mounted on wheels running on a track; but are usually supported on rollers running on plank or timber runways laid down in advance of the driver. If the ground is very irregular, it must be either graded, or the timber runways for the driver must be supported by cribbing or blocking so as to give a level runway for the driver. The building of such a runway often retards the work of land-driving.

Excepting where the driving is exceedingly hard, the hammer is actually at work but a small fraction of the day at best. The contractor should, therefore, exercise his wits to reduce the lost time.

There are no very reliable data as to the relative effectiveness of the blows of steam-hammer drivers and friction-clutch drivers, but the following data by Mr. N. E. Weydert may prove of value:

In driving piles in Chicago, piles 54 ft. long were driven 52 ft., of which 27 ft. were in soft clay, and 25 ft. in tough clay. Each pile averaged 13 ins. in diameter. Using a Nasmyth steam hammer, striking 54 blows per minute, with a weight of 4,500 lbs. falling 3½ ft., it required 48 to 64 blows to drive the last foot when a follower 20 ft. long was used on top of the pile; but, without a follower, it is estimated it would have taken only 24 to 32 blows to drive the last foot. After a pile had stood 24 hrs. it required 300 to 600 blows of the hammer on the follower to drive it 1 ft.

In the same soil, using a 3,000-lb. drop hammer falling 30 ft., and striking a follower 20 ft. long, it required 16 blows to drive the

last foot; but with the same hammer falling 15 ft., it required 32 to 36 blows on the follower to drive the pile the last foot.

The piles were tested with a load of 50 tons each for two weeks and showed no settlement.

The Steam Hammer vs. the Drop Hammer.—Some 50 years ago, when the Nasmyth steam hammer came into prominence as a pile driver, it was predicted by engineers who had seen it that the days of the rope hoisted hammer were numbered. Nor is it uncommon to read similar predictions even to this day. That the steam hammer weighing two tons and striking 60 blows a minute is a very effective machine no one can deny, but what appears to have been overlooked by many engineers is the fact that in nearly all driving of piles on land, a very small fraction of the working day of a pile-driving gang is spent in actual driving. This is particularly the case in building pile trestles with a railroad pile driver.

Records that I have kept show very clearly how little time is ordinarily spent in pile driving on trestle work, using the ordinary railroad pile driver with a friction-clutch engine. Each trestle bent consisted of four piles driven about 10 ft. into firm, dry earth, and bents were 15 ft. c. to c. It took about 20 blows of a 2,800-lb. hammer falling about 18 ft. to drive each pile, and, once the pile was in the leaders, these 20 blows were delivered in from 1 to 2 minutes, depending upon minor delays in keeping the pile plumb. The piles were not ringed. Hence we may say that in so far as the actual time of driving four piles was concerned, only 8 minutes were thus consumed per bent at the most. About 4 or 5 minutes were required to get each pile into the leaders, thus consuming some 20 minutes per bent.

Tabulating the time consumed in performing each detail we have:

	Minutes.
(1) Getting 4 piles into leaders	20
(2) Driving 4 piles	8
(3) Straightening and bracing the piles	27
(4) Leveling and nailing guide strips for sawing off	10
(5) Sawing off 4 piles	12
(6) Putting on cap and drift bolting it	13
(7) Pulling 3 stringers forward from last bent	11
(8) Putting in 2 more stringers that overhang	20
(9) Putting in 1 tie and spiking rail	4
Total time on one bent	125

Item (4) was unnecessarily long, due to the hair-splitting methods of the Y-level man, who was giving the cut-off. Even after the cleats to guide the saws were nailed on, he had them lowered ⅛-in.

Items (3) and (5) may frequently be reduced very materially, and always would be on contract work, but on work done for a railroad company, as this was, the end of the 10-hr. day will find only 4 to 6 bents built under the conditions here given. If, however, we assume a bent of four piles built in 100 minutes, we see that only 8 minutes of that time will be consumed in actual driving. In other words, only three-quarters of an hour out of the 10 hrs. is spent in hammering the pile. This will doubtless be surprising to many engineers, and particularly to those who have been impressed

by the speed of the Nasmyth steam hammers. Under a hustling, wide-awake contractor, the writer has seen 10 bents driven and completed in a day with a friction-clutch driver; but even under such conditions the hammer was actually at work driving less than two hours.

It seems quite clear from the foregoing discussion, that maintenance-of-way engineers should look not to improvements in the form of hammer mechanism, but rather to improvements in the mechanism and methods of handling the piles, caps, stringers, etc. Very much can be accomplished in this respect by having a well-organized force with a clear-headed foreman at its head. In the example just cited the item of straightening piles was exceedingly expensive in time, in that it consumed nearly half an hour. This was largely due to the fact that the foreman did not appreciate the importance of sawing the pile heads square. He simply put the piles into the leaders with the heads rough sawed as they came from the forest. In one case the pile had a large prong of splintered wood projecting above the partly sawed head. Haste never makes more waste than in neglecting to square the pile heads, and guide the pile properly while driving it.

In this particular instance, since the driving was across dry land, the foreman should have secured a team with which to "snake" piles and timbers up alongside of or directly in front of the driver. Then the pile rope or "runner" could have been quickly hooked on to a chain already fastened around the pile or timber to be moved, with a saving of 50% in the time spent in getting material to place. It does not pay to make a team out of a pile driver and a gang of men.

Instead of spending 13 minutes getting a cap to place and drift-bolting it, not more than 6 or 7 minutes need have been so consumed. Two men can cross-cut a pile in 4 or 5 minutes, hence with eight men on four saws, item (5) can be reduced at least one-half. Running around looking for saws, mauls, drift bolts, etc., is one of the greatest causes of delay. For this reason there should be a man whose duty it is to bring tools and put them away immediately after they have served their purpose. The two leader men on the driver might well attend to the tools.

We see, by this method of timing, why the Nasmyth steam hammer has failed to displace the friction-clutch hammer on trestle work, and we see that if any improvement is desirable in driver design it is not in the hammer mechanism, but rather in the means of mechanically handling the timbers. Finally we see that organization of the force is quite as essential as improvement in mechanism, while it possesses the decided advantage of costing nothing except what may be paid for a better quality of brain work.

From this discussion it should not be inferred that the steam hammer has no field of usefulness, for it has. Its field, however, is in scow or land driving, where a great number of foundation piles are to be driven close together, and especially where a great number of blows must be struck to secure the desired pile penetration.

Cost of Making Piles.—Two men can cut down and trim 17 oak piles per day, each pile being 20 ft. long. Where the men are paid $1.75 per 10 hrs., the labor cost of making the piles is practically 1 ct. per lin. ft. To this must be added the cost of hauling and freight to the place where the piles are to be driven.

For weight of piles, see the fore part of this section.

Life of Pile Driver Rope.—Mr. George J. Bishop kept some records of pile driving on the C., R. I. & P. Ry. in 1897, to determine the life of manilla rope. The drum of the friction pile driver engine was 14 ins. diam., also the sheave at the top of the leads, and the sheave at the front of the pile driver was 20 ins. The hammer weighed 3,000 lbs. The rope was of three different makes, all 1¼ ins. diam. Common manilla 3-ply rope made the best showing. The length of rope was 125 ft. and its weight ranged from 74 to 95 lbs., averaging 85 lbs., or nearly 0.7 lb. per ft. The price of the rope was 6½ cts. per lb. or $5.53 per average rope. Ten ropes were used up in driving 1,335 piles to an average penetration of 20 ft. Hence each rope averaged 133 piles, or a cost of 4 cts. per pile for rope. However, 5 of the ropes averaged only 101 piles each, and 5 averaged 166 piles each.

Cost of Driving Piles With a Horse Driver.—This work consisted in driving 219 piles, 2 ft. centers, to form the protecting toe of a slope-wall. The hammer weighed 2,000 lbs., and was raised with block and tackle by horses. Two teams were used alternately. As soon as the hammer was tripped, two men pulled back the hammer rope hand over hand, and hooked it on to the second team while the other team was returning. In this way the blows were delivered almost twice as rapidly as when one team only is used. The driver was supported on wooden rollers sheathed with iron and provided with sockets into which bars could be inserted for turning the rollers. The rollers rested on planks laid on the ground which was comparatively level and required no staying or grading to secure a level runway for the driver. Pine piles, 15 ft. long, were driven in a stiff clay to a depth of 13 ft.

The average number of piles driven per 10-hr. day was 21, but the best day's record was 30. The cost was as follows per day:

5 laborers, at $1.50	$ 7.50
1 foreman, who worked	2.50
2 teams and drivers, at $3.00	6.00
Rent of driver	2.00
Total, for 21 piles, at 85 cts.	$18.00

The piles cost 10 cts. per ft. delivered; and the contract price was 24 cts. per ft. delivered and driven.

On another contract under my direction, where piles were spaced 10 ft. centers and driven 12 ft. into gravel along the sloping bank of a river, it was necessary to do more or less grading and blocking up to secure a level runway for the pile driver. Four men and a pair of horses averaged only 6 piles per 10-hr. day, making the cost about $1.50 per pile for the labor of driving. This gang was too small, and worked deliberately.

Cost of Driving Foundation Piles for a Building.—On this work, which consisted in driving long piles for the foundation of a building in Jersey City, a pile driver mounted on rollers was used. The leaders were 60 ft. long, and provided with two head sheaves, one for the hammer rope and one for the rope used in hauling and raising the piles. The hammer weighed 2,100 lbs.; and the engine was a double-drum friction-clutch. The piles were of spruce 50 ft. long, and were driven their full length in soft clay. For the first 10 ft. the piles were driven without ringing. When the pile head reached the bottom of the leaders, a short wooden follower was used for the last 10 to 25 blows. The pile ring was then pulled off the pile by a short iron peavy lifted by the pile rope. The piles were stacked up in the street about 100 ft. away from the driver, and were "snaked over," when wanted; the pile rope being used for the purpose. For the first few blows the hammer had a fall of only 5 ft., and about 25 blows per min. were delivered. But after that the fall of the hammer was 12 ft., and about 18 blows per min. were delivered. It required about 110 blows to drive a pile its full 50 ft. The time required to drive one pile was as follows:

	Minutes.
Hooking on dragging pile to driver	5
Hoisting pile and getting it in place	2
Hammering pile	6
Putting ring on pile	1
Placing follower on pile	½
Removing follower from pile	1
Removing ring from pile	½
Shifting pile driver 2 ft.	1
Total time per pile	17

It will be observed that the hammer was actually engaged in hammering not much more than one-third of the total time. When everything was working smoothly 35 piles were driven in 10 hrs., but the output frequently fell below 30 piles in a day, due to sundry slight delays and accidents.

The cost of operating the driver was as follows:

1 engineman	$ 3.00
1 man up the ladder	1.50
4 men handling and guiding pile	6.00
1 man sharpening piles	1.50
1 foreman handling pile rope, etc.	4.00
½ ton coal, at $6	2.00
Total per day for labor and fuel	$18.00
Rent of pile driver	3.00
Total, at 60 to 70 cts. per pile	$21.00

This does not include cost of delivering and removing the pile driver.

The Construction and Cost of a Small Pile Driver.*—Frequently a pile trestle must be built, and the number of piles to be driven may not warrant buying, or even hiring, a pile driver of ordinary size.

*Engineering-Contracting, January, 1906.

In such cases a small driver may be built at a nominal cost, and it will do very effective work where the piles are to be driven to a moderate depth. Such a driver (Fig. 5) was built by the managing editor of this journal some years ago, and a description of it will be given.

The "leads," or "gins," that guided the hammer were made of 4-in. x 6-in. sticks, 30 ft. long. The hammer was of cast iron and weighed only 1,200 lbs. The rope that raised the hammer was 1-in. manilla. One end of this hammer rope was fastened to the "nippers" that clutched the lugs on the hammer. The other end of the

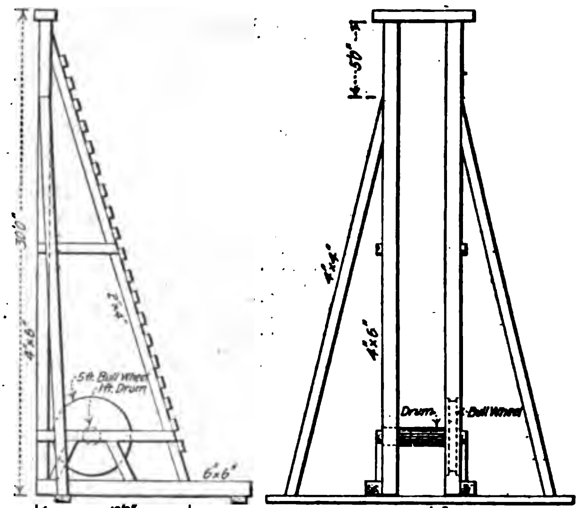


Fig. 5.—Small Pile Driver.

rope passed through a pulley and around a wooden drum 12 ins. in diameter. At one end of this wooden drum was fastened a wooden "bull wheel," 60 ins. in diameter. Another rope was wound around this "bull wheel," and a horse was hitched to the rope. The horse easily raised the hammer to the top of the "leads," where the "nippers" were automatically tripped, allowing the hammer to fall. The reader will note that only one pulley block was used. The use of a drum and "bull wheel" made it unnecessary to get any more blocks, and thus reduced the first cost; but, what is even more important, a "bull wheel" and drum does not consume the power of the horse in friction to any such degree as is the case where pulley blocks are used.

The bill of lumber for the driver is as follows:

Piece.	in.	in.	ft.		Ft. B. M.
2—	4 x	6 x	30	(leads)	120
1—	6 x	6 x	4	(cross-piece)	12
2—	6 x	6 x	16	(base)	96
2—	2 x	4 x	32	(ladder)	43
2—	2 x	4 x	2	(ladder rungs)	24
2—	4 x	4 x	26	(sway braces)	64
1—	2 x	4 x	20	(long front sill)	13
1—	2 x	4 x	14	(short rear sill)	3
1—	12 x	12 x	4	(drum)	48
30—	1 x	12 x	6	(bull wheel)	180
				Total	603

About 24 bolts, ½ x 8 ins., were used, and a few pounds of nails. The wooden drum and "bull wheel" required more time to make than all the rest of the driver. The drum was shaped out of a 12-in. x 12-in. stick, but was left square where the "bull wheel" was to be fastened on. At each end of the wooden drum, a wooden axle, 4 ins. in diameter and 6 ins. long, was cut out; and these axles were fitted to wooden bearing blocks, and were well daubed with axle grease. The wooden "bull wheel" was made of five layers of 1 in. by 12 in. planks spiked together; one layer running one way, the next layer in the opposite direction. First, three of these layers were spiked together, and a 5-ft. circle was marked on them. Then with a key-hole saw the 5-ft. wheel was cut out. On each side of this wheel was spiked another layer of plank and sawed to a circle 5 ft. 8 ins. diameter. These two layers formed the rims of the "bull wheel" and kept the "bull rope" from slipping off.

Two carpenters and two laborers built this driver in two days, at a cost of $18 for labor. The total cast was:

700 ft. B. M., at $20	$ 14.00
Bolts and nails	2.00
Labor	18.00
1,200-lb. pile hammer	50.00
1 pair nippers	5.00
1 snatch block	3.00
240 ft. of 1-in. rope	10.00
Total	$102.00

The driver weighed 1¼ tons, exclusive of the hammer, and was easily loaded on a wagon.

The cost of driving piles with it is given in the following paragraph.

Cost of Driving Piles for Wagon Road Trestles.—It was necessary to drive piles for a number of wagon road trestles across ravines, which were often separated by several miles. A light pile driver that could readily be moved from place to place was built, as described on page 1000.

Piles were driven in bents of three piles each, bents 20 ft. apart. In fairly hard ground the piles were driven only 5 or 6 ft. deep. Due to the irregularity of the ground, in nearly all cases it was necessary to build a light scaffolding on which to run the driver across each creek. This scaffolding was made of sticks cut from

the forest alongside, and cost nothing except for labor, which is included in the cost of $1 given below. The young contractor would be apt to overlook this item of scaffolding, but it should always be remembered that a driver of this kind must have a level runway on which to work, and, if the ground is irregular, it must either be graded or scaffolding put up. Usually scaffolding is cheaper than grading.

The crew consisted of 4 men and 1 horse. It would take them about 2 days to move the driver 4 miles over poor roads, and erect a staging upon which to drive a seven-bent trestle. Then they would average 10 piles driven per 10-hr. day. The cost of actual driving was about $1 per pile, wages being $10 a day for the crew; to which must be added another $1 per pile for lost time moving driver from one trestle to the next and building staging. This was the average cost on six trestles, 84 piles being driven.

Cedar piles were largely used for this work, as the driving was light, and as the durability of cedar is greater than other woods. After driving the piles, 2 men would saw off the heads of 18 piles in 3 hrs., at 6 cts. per pile. These piles averaged 20 ft. in length, and with axmen at $2 a day each, they were cut down and trimmed for 25 cts. a pile, and hauled 3 miles over rough roads for 50 cts. more per pile.

I found it economic to sublet the pile driving to a reliable carpenter who would work with his gang of three men, and earn good wages for himself and crew if paid $2 for driving each pile, including all moving and building of staging. The work just described was done in this way. Work handled thus generally insures activity on the part of small gangs of men and reduces the charges for superintendence to a very small percentage.

Cost of Driving Piles for Trestle Renewals.*—Mr. G. H. Herrold is author of the following work done on the Chicago Great Western Ry. in Minnesota.

I have compiled the following statement [the complete tabulation of each day's work is given in *Engineering-Contracting*, but not reprinted here] from daily reports of the performance of pile driver working on pile bridge renewals during the 1905 season, to show the number of piles driven each day and the labor cost per pile, the total labor cost per day, the delays and the average labor cost per pile for the season's work.

I have done this to show the great variation in the cost per pile, comparing one day's work with another, and yet the relative low average cost of the total work done, and, to determine a basis for estimating more closely the cost of pile renewals.

A 3,000 lb. drop hammer was used; 25 bridges were opened, the work on each bridge varying from complete renewal to one bent renewal. Driver was supplied with piling by making shipments, by bridges, as far as possible, and one car load of assorted lengths, as extras, was kept in work train.

Engineering-Contracting, Mar. 23, 1906.

Three hundred and ninety-one piles were driven in 32 10-hr. working days, or an average of 12.2 piles per day, the maximum cost per pile for any day was $10.57, and the minimum cost was $1.28. The cost per pile for the season was $2.88. The piles varied in lengths from 20 ft. to 40 ft., and were driven 9 to 21 ft. in the ground.

The average daily expense was as follows:

	Per day.
Pile driver crew, wages	$21.00
Work train, wages	14.50
Total, 12.2 piles, at $2.88	$35.50

In the 32 days' work, 80 hrs. were lost by delays due to traffic, etc., or about 25% of the working time.

The character of the driving varied from shell rock (requiring cast shoes) quick sand, and indurated clay to perfect material.

The train crew consisted of engineer, fireman, conductor, and brakemen.

The pile driver crew consisted of a foreman, engineer, fireman and eight men.

The men were cared for in boarding cars which were self-supporting.

The following is a type of the daily performance report:

David, Sept. 26, 1905.

Division Engineer.

Drove 16 piles Br. A188 and transferred piling in KC&MB 690 to a local flat. Worked 10 men, expense $21.48. Delayed 2 hrs., 40 mins., as follows: 40 min. by No. 274; 50 min. running for water; 30 min. by No. 203; 40 min. by No. 204. Will finish A188 to-morrow, want orders.

Pile Driver Foreman.

Cost of Driving Piles for a Trestle, N. P. Ry.—Mr. E. H. Beckler gives the following data on driving piles for a railway trestle and three truss bridges on the N. P. Ry., at Duluth, Minn., by contract in 1884. The work was all done in the winter, and about 2,340 piles were driven, of which 460 were in foundations. The trestle was 5,000 ft. long. A pile driver, having leaders 65 ft. long, and a 2,600-lb. hammer, was used. The piles were of Norway and white pine, the average length being 51 ft. From 50 to 150 blows were struck on each pile. With a 20-ft. fall the hammer struck 7 blows per min. The penetration was 10 to 42 ft. The average cut-off was 5 ft. for the trestle piles. The pile driven engine was mounted on the driver platform to give stability and for ease of moving. A 900-lb. follower was used in driving some of the piles, but it was found to reduce the penetration of each blow about 20%, and it did not save the heads of the piles from more or less shattering.

Some piles were driven butt down, but it added 25% to the cost of driving; and it was believed that the small end, being exposed would decay faster than the butt end. Moreover, the area of the

small end was so small that the pile would not stand heavy driving without shattering.

The cost of operating one pile driver was about $38 a day and from Dec. 11 to Mar. 5 the record of its work was as follows:

	Per pile.
202 piles (32 ft. long), 19.2 piles per day	$2.25
134 piles (44 ft. long), 23.3 piles per day	1.65
364 piles (60 ft. long), 25.1 piles per day	1.50
379 piles (66 ft. long), 19.2 piles per day	1.95
73 piles (65 ft. long), 22.5 piles per day	1.85

These costs represent the cost to the contractor.

As many as 30 piles a day for 4 consecutive days were driven. The average cost of driving these 1,152 piles, it will be seen, was nearly $1.75 per pile.

The driving was done after the ice had formed in the bay, and the pile driver was supported by the ice during driving.

The soil was 7 ft. of clay under which was sand. Before the work was begun, test piles were driven from a scow along the line of the trestle 300 ft. apart. This enabled the engineers to make out an accurate bill of pile timber for the work.

It was found that Norway pine piles stood the driving in cold weather (as low as —15° F.) much better than white pine; for, when wood freezes, it is brittle.

The test piles were nearly all broken off several feet below the ground level, by the side thrust of the ice that formed to a thickness of 4 ft. after the piles were driven. Three test piles were pulled up by the ice, although they had been driven 40 ft. into mud. The combined strength of four piles in a bent was required to resist the lateral thrust of ice pushed by the wind. The ice was unable to lift the piles once the trestle was finished.

Cost of Pile Driving, O. & St. L. Ry.—Mr. A. E. Buchannan gives the following data of work done, Oct. 22 to Dec. 17, 1889, on the Omaha & St. Louis Ry., by company labor. There were 46 days worked, the actual working time being 6 hrs. 52 mins. per day. The railway driver drove 1,267 piles in these 316 hrs. of which time 14 hrs. were lost in lowering the leads 344 times, or 2½ mins. each time. The average time to drive a pile, it will be seen, was 15 mins. The average depth driven was 14 ft. The work was on 41 different trestles, each averaging 101 ft. long. Wages were $2.40 for enginemen, $2.00 for fireman, and $1.50 to $1.75 for laborers. The cost of the 46 days' work was:

Wages	$1,684
Fuel, etc.	262
Total, 1,267 piles, at $1.54	$1,946

The poorest day's work was 11 piles; the best, 44 piles; the average, 28 piles.

Cost of Pile Driving, C. & E. I. Ry.—Mr. A. S. Markley gives the following data relative to the cost of driving 436 piles on 16 jobs,

averaging 27 piles on each job. The work was done in 1902 for the C. & E. I. Ry., using a self-propelling railway pile driver made by the Industrial Works, Bay City, Mich. No locomotive was required as the driver could run at a speed of 10 miles an hour and pull 5 cars on a level road. The leads were 47 ft. long; the hammer, 2,900 lbs.; the hoisting rope, 2-in.; and the engine 30-hp., double cylinder. The leads could be raised in 2 mins. The engineman received $2.50 a day; the fireman, $1.50; the rest of the men were laborers, except the foreman. The average cost of driving each pile was 75 cts.; and each pile averaged 24 ft. long, although the range was from 14 to 42 ft.

The Record for Rapid Driving on the O. & M. R. R.—As illustrating what can be done under favorable conditions where men are rushing their work, a record given by Mr. L. C. Fitch, Engineer of Maintenance-of-Way, Ohio & Miss. R. R., is interesting. A pile driver crew drove 28 piles (7 bents of 4 piles each) in 3 hrs., at a cost of 30 cts. per pile. The piles averaged 21 ft. long and were driven 15 ft. into the ground.

Cost of a Pile Trestle, Sheet Piles, Etc.—Mr. Henry H. Carter gives the following costs of building a trestle across a pond in Massachusetts. The work was done by contract, occupying five months, beginning November, 1883, and ending April 9, 1884. The piles were driven in bents of 8 piles to the bent, bents 4 ft. apart, and capped with 10 x 10's 35 ft. long, notched down (dapped) 2 ins. on each pile. On the caps were laid four lines of 8 x 10-in. stringers, and on these were laid the ties for a double track road for contractor's dump cars. This trestle was filled with gravel, and afterward all but the two outer piles in each bent were cut off 7 ft. below water and used as a foundation for a masonry conduit. The average length of the 3,750 piles driven was 37 ft., about 25% of the piles being over 45 ft. long. With the hammer falling about 12 ft., 318 of the piles penetrated less than 1 in. under the last blow (very hard driving); 950 piles penetrated 1.3 to 2.7 ins. under the last blow (hard driving); 2,016 piles penetrated 3 to 4 ins. under the last blow (medium driving); and 141 piles penetrated over 4 ins. under the last blow (easy driving). In general the piles were driven through several feet of very soft mud and 12 ft. into the hard bottom. The piles were driven by two floating pile drivers supported on a raft made of timbers and empty oil barrels. The cost of the work was as follows:

Making Pile Driver:

Foreman, 7 days, at $3.25	$ 22.75
Engineman, 7 days, at $3.25	22.75
Laborers, 15 days, at $1.75	26.25
Carpenter, 14 days, at $2.25	31.50
Carpenter, 18 days, at $2.00	36.00
Gins	124.00
Floats	314.95
Total making driver	$578.20

The cost of building this driver if distributed over the 3,638 piles

driven, amounts to nearly 16 cts. per pile. The other costs were as follows:

Loading and Transporting Piles:

Foreman, 96¼ days, at $2.00	$ 192.50
Laborers, 449 days, at $1.75	785.75
Horse, 104¾ days, at $1.50	157.12
Sleds	3.50
Total loading, etc.	$1,138.87

Pile Driving:

Foreman, 82 days, at $3.25	266.50
Foreman, 118½ days, at $3.00	355.50
Foreman, 95 days, at $2.50	237.50
Engineman, 87 days, at $3.25	287.75
Engineman, 103½ days, at $2.50	258.75
Topman, 166 days, at $2.00	332.00
Topman, 17 days, at $1.75	29.75
Deckhand, 116½ days, at $2.25	262.12
Deckhand, 255¼ days, at $2.00	510.50
Deckhand, 280 days, at $1.75	490.00
Laborer, 20 days, at $1.00	20.00
Carpenter, 177 days, at $2.25	398.25
Carpenter, 172 days, at $2.00	344.00
Freight on pile drivers	75.00
Coal, 35 tons, at $6.40	224.00
Use of plant, 180 days, at $1.50	270.00
11 M spruce braces, at $14	154.00
872 lbs. spikes in braces, at 3 cts.	26.16
Tools	120.00
Total driving	$4,661.98

Piles:

3,638 spruce piles (av. 37 ft. each), at $2.26	$8,221.88
Grand total (excl. driver)	$14,022.53

The loading and transporting of the 3,638 piles cost $0.32 per pile. The driving cost $1.30 per pile, the average number of piles driven being 20 per day. The cost of each pile averaged $2.26. The total cost of each pile driven was $4.04, including cost of making scow, interest on driver, labor, fuel and cost of pile. The use of plant at $1.50 a day is too low an estimate under ordinary conditions.

The cost of the materials and labor for caps, stringers and ties (there were no sway braces) was as follows:

Transporting Timber:

Foreman, 19 days, at $2.00	$ 38.00
Laborer, 89 days, at $1.75	155.75
Laborer, 4 days, at $1.50	6.00
Horse, 20 days, at $1.50	30.00
Sled	1.50
Total transporting timber	$ 231.25

Labor on Caps and Stringers:

Foreman, 16 days, at $3.25	$ 52.00
Foreman, 20 days, at $2.50	50.00
Carpenter, 60 days, at $2.25	135.00
Carpenter, 58 days, at $2.00	116.00
Total labor on caps, etc.	$ 353.00

Caps and Stringers:	
159 M spruce, at $16.10	$2,559.90
12 M spruce bolsters, at $13.50	162.00
3.6 M spruce plank, at $14.00	50.40
10,490 lbs. bolts, at 2⅝ cts.	283.23
3,830 lbs. bolts, at 3 cts.	114.90
88 lbs. spikes, at 3 cts.	2.64
Building derricks	5.00
Tools	28.50
Total labor and mtls. for caps and stringers	$3,559.57

The cost of transporting timbers to the trestle ($231.25) applies not only to the 175 M of caps and stringers, but also to 24 M of ties and 27 M of sheet piling and wales, making the cost of transporting practically $1 per M. The other labor involved in placing the caps and stringers ($353) after delivery, is equivalent to $2 per M, making a total of $3 per M for the labor on the caps and stringers. The cost of placing the ties was as follows:

Placing Ties:	
Laborer, 4½ days, at $1.00	$ 4.50
Laborer, 6 days, at $1.50	9.00
Laborer, 51¾ days, at $2.00	103.50
Total placing ties	$117.00
Ties:	
24.18 M spruce ties, at $14	$338.52
540 lbs. spikes, at 3 cts.	16.20
Total labor and mtls.	$471.72

From this it appears that the cost of placing ties was nearly $5 per M (or 21.3 cts. per tie) to which must be added $1 per M for loading and transporting.

The cost of sheet piling was as follows:

Sheet Piling:	
25.5 M sheet piling, at $18.60	$474.30
1.2 M spruce wales, at $16.00	19.20
205 lbs. spikes, at 3 cts.	6.15
Interest on pile driver, 16 days, at $1.40	22.40
3 tons coal, at $6.40	19.20
Foreman, 16 days, at $3.25	52.00
Engineman, 16 days, at $3.25	52.00
Topman, 16 days, at $2.00	32.00
Deckhand, 16 days, at $2.00	32.00
Deckhand, 40¾ days, at $1.75	71.81
Carpenter, 32 days, at $2.00	64.00
Total sheet piling	$844.56

The cost of driving the 25.5 M and placing the 1.2 M was nearly $13 per M. This sheet piling was 4-in. tongued and grooved, driven for two culverts.

The cost of sawing, dapping (notched 2 ins.) and fitting 280 caps for 280 pile bents of 6 piles to the bent was as follows: Cost to saw off piles, and fit caps, $2.95 per cap, or $2 per M (for each cap was 10 x 10 ins. x 18 ft.). The piles were sawed off at the bottom of a wet trench, and it cost 90 cts. per bent to saw away the earth. Carpenters received $2.50, laborers $1.25, and foreman $3.50 a day. The gang consisted of 1 foreman, 3 laborers and 4 carpenters.

These caps were covered with a platform of 4-in. spruce plank run lengthwise of the trench, laid to break joint, and spiked to the caps with 8-in. cut spikes. This platform was laid with a force of 1 foreman, at $3.50; 8 laborers, at $1.50, and 1 carpenter, at $2.50. The cost of laying 900 M was $7.40 per M. The contractor doing this work failed.

Cost of a Pile Docking.—This work consisted in driving a row of oak piles, 25 ft. long and 5 ft. centers, to an average depth of 10 ft. into gravel. The piles were sheeted on the rear with 3-in. oak plank laid horizontally and breaking joints. A waling piece, of 10 x 12-in. oak, was bolted along the front face of this docking, and anchored back to stone deadmen. The anchor rods were 1¾-in., spaced 10 ft. apart. Back of this docking an earth fill was placed, but the following costs relate only to the timber work. A pile driver, mounted on rollers, and operated by a friction-clutch engine, was used. The daily cost of operation was as follows:

7 men, at $1.50	$10.50
1 foreman	3.00
1 pair of horses	1.50
Rent of driver and engine	3.00
¼ ton coal, at $4	1.00
Total, 10 piles driven, at $1.90	$19.00

The piles were of oak and two of the men peeled and pointed them and square-sawed the heads. The horses were used to drag the piles up to the driver. There was some grading and scaffolding work necessary to provide a level runway for the driver. The foreman was not a good manager, and the cost was much higher than it should have been. On one day when the work was pushed and when conditions were favorable, 25 piles were driven.

The labor cost of placing the sheet planking and wale piece was $4.50 per M, about 80% of the timber being the 3-in. planking. This work was done by common laborers working in pairs, at $1.50 each per 10-hr. day. The piles were not always plumb and seldom spaced exactly, so that a measuring pole had to be used to fit each plank, and every plank had to be sawed separately by the men. Had the engineer so designed the work that the planks could have been set on end, like sheet piling, all this fitting and sawing of individual planks could have been avoided, with consequent reduction in the cost. Moreover there would have been less wastage of plank. Such a design would have necessitated two more small-sized wale pieces, but it would have made easy the removal of any single plank at any time for repairs due to rotting. In boring the oak wale pieces and piles with a 1¾-in. ship auger, a man would bore 12 ins. in 5 mins. It took 5 mins. for two men to cut off a 10 x 12-in. oak stick using a crosscut saw.

It may be well to note that the plans called for the driving of 3 x 8-in. oak sheet piling to a depth of 5 ft. by hand, using wooden mauls. It was found impossible to drive these planks more than 2 ft. into the gravel without battering the heads to pieces.

Data on Driving Plumb and Batter Piles, New York Docks.—Mr. Charles W. Raymond gives the following data on the driving of piles for docks, Hudson River, New York City, prior to 1880: Piles were driven with a scow pile driver, the scow being 3 x 20 x 42 ft., provided with leaders 50 ft. long. The engine was a 10-hp. friction-clutch hoisting engine, with double cylinders, 6 x 12 ins. The boiler was 15 hp. upright. A crew of 8 men worked 8 hrs. per day for the city, and drove 10 to 15 piles per day. The piles averaged about 65 ft. long, and were driven 55 to 60 ft. below mean low water, penetrating about 10 ft. of gravel and cobbles (6-in. and less) that were filled in over the dredged area before driving. Then the piles penetrated about 25 ft. of river muck, making a total penetration of 35 ft. There was no difficulty in driving through the cobbles and gravel without brooming the piles. All piles were sharpened, and their heads were squared. To indicate the kind of driving, two records of 50 piles show that 230 blows of the hammer were required to secure a penetration of 38 ft., or 180 blows to secure a penetration of 33 ft. The last foot of penetration required 13 to 14 blows of a 3,000-lb. hammer falling 8 ft. (not freely, but with the hammer rope).

A special driver, with leaders inclined 1 to 6, was used to drive batter piles, and the average number of piles driven per day was about half as many as in driving plumb piles, or 5 to 7 piles per 8-hr. day. The number of blows per batter pile was somewhat greater than per plumb pile, but by no means enough greater to account for the slower driving, which was probably due to difficulty in getting the batter pile properly started.

Data on Driving Piles for Docks, New York.—Mr. Eugene Lentilhon states that in 1896 the following comparative records were made with a drop hammer and a Vulcan steam hammer: The driving was for a dock on the Hudson River, New York City, and was very hard driving, the material being 10 ft. of cobbles underlaid by sand and gravel. The piles were spaced 3 ft. apart, and driven from scows. The drop-hammer, friction-clutch machine had a crew of 10 men. It required 175 blows of a 3,300-lb. hammer falling 10 ft. to drive a pile; and 15 blows were struck per minute, hence the actual time of hammering a pile was about 12 mins. The piles were 55 to 60 ft. long and penetrated 21 to 28 ft. The crew averaged 12 piles per 10-hr. day.

As compared with this crew of 8 men, using a Vulcan steam hammer, averaged 18 piles per 10 hrs. The machine weighed 8,400 lbs., and the striking piston weighed 4,000 lbs. and had a drop of 3½ ft. It struck 60 blows per minute, and some piles required as many as 1,200 blows. Mr. Lentilhon does not make it clear why the steam hammer was more effective than the drop hammer. It is probable, however, that there were fewer delays in straightening up the pile during driving when a steam hammer was used. He states that there were two objections to the steam hammer, one of which was the frequent loss of the "cap" or "saucepan," or "hood," by dropping into the water, and the rapidity with which the "cap"

was worn out. Only 38 piles were driven with each cap before it was worn out. The second objection was the impracticability of driving crooked piles.

Cost of Pulling Piles, Driving Piles and Timberwork.*—In 1899 the city of New York let a contract for making alterations to the temporary bridge over the Bronx River near Westchester avenue, Bronx Borough. The contract price was $950. The work consisted of the tearing out of the old pivot pier, cutting off one span of the west trestle approach and adding one span to the east side. Fig. 6 shows the extent of the work.

The old pivot pier was constructed of piles driven to rock through four or five feet of hard material, probably disintegrated rock. The piles were sway braced, were capped by 12 in. x 12 in. timber

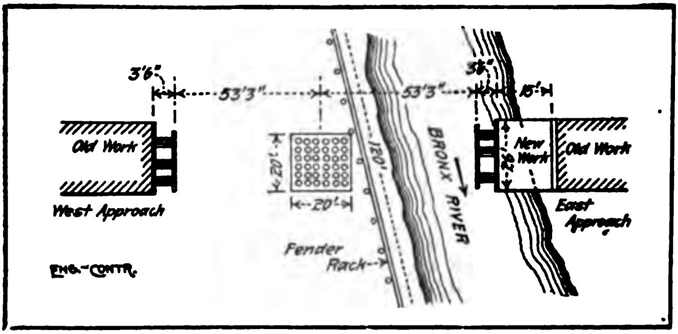


Fig. 6.

and had a 6 in. deck on top of the caps. A fender rack about 90 ft. long was also removed. This rack consisted of piles, 8 ft. center and timber, 3 in. x 12 in., bolted to the piles.

The contractor's plant consisted of a pile driver and scow and a land driver operated from the scow. According to the terms of the contract all timber in good condition could be used over again. Work was begun June 14, and the weather was favorable for good work.

The first work done was the tearing out of the old pile pivot pier and the fender rack. In this work the scow pile driver was used in pulling the piles, about 45 piles being removed in this manner. Such of these piles as were in good condition were used in the new work. In addition one span of pile trestle was cut off in the west trestle approach, the timber being sawed off close to the ground. A total of about 10 M ft. B. M. was removed, the labor cost being as follows:

**Engineering-Contracting*, June 13, 1906.

	Hours.	Rate, cts.	Total.
Foreman	48	45	$21.60
Engineman	24	35	8.40
Dock builders	96	27½	26.40
Watchman	30	15	4.50
Total 10 M ft. at $6.09			$60.90

It was necessary to excavate a small amount of mud in order to allow the pile driver to float in sufficiently near the pivot pier, and also to allow the placing of the sway bracing as low as possible. The depth of the cutting was 3 ft. and about 30 cu. yds. of material was removed. The labor cost was as follows:

	Hours.	Rate, cts.	Total.
Foreman	4	45	$1.80
Engineman	2	35	.70
Dock builders	8	27½	2.20
Watchman	2	15	.30
Total, 30 cu. yds. at 16.6 cts.			$5.00

In driving the piles the scow pile driver and the land driver were used, the latter, however, was used only in driving the piles in the bank bents, 8 piles being so driven. In all 83 piles were driven. The piles were of spruce, about 25 ft. long, and were rather slender. They were driven through about 5 ft. of disintegrated rock, above which was soft mud, to solid rock. It took from 20 to 25 blows of the hammer to drive each pile. The hammer was raised by a friction hoist, and fell with hoist cable attached.

The labor cost of driving the piles is shown in the accompanying table.

LABOR COST OF DRIVING THE PILES.

	Hours.	Rate, cts.	Total.	Cost per pile.
Foreman	82	45	$ 36.90	$0.44
Engineman	41	35	14.35	.17
Dock builders	171	27¾	47.03	.57
Watchman	40	15	6.00	.07
Total			$104.28	$1.25

LABOR COST OF FRAMING AND PLACING TIMBER.

	Hours.	Rate, cts.	Total.	Cost per M. ft. B. M.
Foreman	166	45	$ 74.70	$5.06
Engineman	88	35	34.80	2.36
Dock builders	365	27½	100.38	6.78
Watchman	128	15	19.20	1.30
Total			$229.08	$15.50

In framing and placing timber about 14,800 ft. B. M. of yellow pine lumber was used. Some of this was new and some was taken from the old work. The piles were cut off and capped, and the stringers and floor in the approaches and the deck of the pivot pier were placed. A railing was built on the approaches and the sway braces and fender rack were bolted into position. Little framing was done. The labor cost of this work is shown in the accompanying table.

The total cost of the work is shown below:

Labor:	
Tearing out old work	$ 60.90
Excavation	5.00
Driving piles	104.28
Framing and placing timber	229.08
Total labor	$399.26
Materials:	
53 piles at $2	$106.00
Timber, 3.6 M ft. B. M. at $30	108.00
Bolts, spikes, etc., 900 lbs. at 5 cts.	45.00
Total	$259.00
Operating Expenses:	
Towing	$ 30.00
Coal for pile driver, 2½ tons at $4	10.00
Repairs to plant	10.00
Total operating expenses	$ 50.00
Total cost	$679.00

As stated previously the contract price was $950.

Work of this character is generally expensive because of the small gang of dock builders employed. The engineman's wages and plant expense, therefore, form a large percentage of the total cost.

Cost of Driving and Sawing Off Piles.—Mr. Eugene Lentilhon gives the following relative to a pile foundation for a concrete sewer, built by the New York City Dock Dept. The piles were driven by a scow driver with a 3,400-lb. hammer, which worked 65 days. Wages were $2.30 for laborers, $3.50 for engineman, and $3.00 for dock-builders, per 10 hrs. The average was 8 piles driven per day, at a cost of $3.90 for labor of driving. The piles were sawed off 1 ft. below mean low water. The dock builders fastened small battens on opposite sides of a pile to guide the saw, and frequently two men during a good low tide sawed off 3 piles. The cost of sawing off was $1.28 per pile.

Data on Driving With a Steam Hammer and Sawing Off Piles.—Mr. Sanford E. Thomson gives the following data on driving and sawing off piles for the Cambridge Bridge, at Boston, in 1901. A Warrington steam hammer, made by the Vulcan Iron Works, of Chicago, was used by the contractors. It weighed 9,800 lbs., and the striking part weighed 5,000 lbs. With 90 to 100 lbs. of steam, the hammer would strike 60 to 70 blows per minute, falling by gravity. The top of the leaders of the scow driver was 75 ft. above the water surface. After a pile was well down, an oak follower, 14 ins. square and 30 ft. long, was placed on the pile to complete the driving, so that the pile head was left 18 ft. below the water surface. The average 10-hrs. work of a driver was 100 piles, but on one day as many as 212 piles were driven in 9 hrs. The piles were 40 ft. long and driven in hard clay.

The piles were cut off 15 to 34 ft. below low water by a rotary

saw mounted on another scow. A 40-hp. engine running at 150 revolutions per minute was geared up to the saw shaft so as to drive the saw at about 450 revolutions per minute. A 42-in. saw was mounted at the lower end of a hollow vertical shaft 4 ins. in diameter and 60 ft. long. This shaft was supported by three pillow-block bearings which were bolted to a spud 14 ins. square and 60 ft. long; so that when the spud was raised or lowered the saw shaft moved with it. The pulley on the saw shaft was arranged to slide on a spline or key, so that the shaft could be raised without raising the pulley. The belt from the pulley ran to another pulley mounted on a short vertical jack-shaft, provided with a bevel gear wheel meshing with another bevel gear wheel on a horizontal shaft driven by the engine. This horizontal shaft was geared to the engine with a link belt. This machine sawed off 600 to 800 piles per 10-hr. day. The spruce piles were 10 ins. diameter.

Cost of Driving Piles for a Swing Bridge.—A steel highway swing bridge, 240 ft. long, and 16-ft. roadway, was to be supported on a pier in the center of the river. The piles were Washington fir, driven to an average depth of 20 ft. in grrvel. The penetration under the last blow of a 2,400-lb. hammer, falling freely 27 ft., was 3 to 4 ins. A scow pile driver was used, and the force to operate it was as follows:

	Per day.
1 engineman	$ 3.00
1 man tripping hammer	1.75
2 men guiding pile	3.50
2 men making ready the next pile	3.50
½ foreman	2.50
⅓ ton coal, at $9	3.00
Total per 10 hrs.	$15.25
Rent of driver	6.00
Total	$21.25

This force averaged 26 piles per 10-hr. day. The foreman supervised another gang of men, so that half his wages were charged to this work. The piles were neither peeled nor sharpened, for I found no economy in so doing. There were 42 piles in the pier, and twice as many more in the pier protection bents upstream and downstream, which also served as falsework upon which to build the bridge. The piles in these bents were sawed off, capped and sheeted with plank. Two men with a cross-cut saw would saw off 30 of the piles in the bents in 10 hrs., at about 12 cts. per pile. The cost of sawing off the piles below water for the pier is given in the next paragraph.

Cost of Sawing Off 42 Piles Under Water.—It was necessary to cut off 42 piles, 4 ft. below extreme low water for the pier work just described. A gravel bar occupied the site of the pier, and, although the water was about 4 ft. deep over the bar at the time of pile driving, it was necessary to dredge this bar at least 4 ft. deeper. A hole 4 ft. deep, and 27 ft. square on a side, was dredged with an ordinary drag scraper equipped with long handles and hauled by the pile-driver engine. The men operating the scraper walked on

a raft. It took 3½ days of the pile driver crew above given, to do this dredging, at $21 per day, or $74. The 42 piles were driven in this hole, after driving 4 piles above the hole and sheeting them with plank to act as a temporary sheer dam to prevent the river current (3 miles per hr.) from filling in the hole with gravel during pile driving. The 42 piles were cut off about 8 ft. under water with a circular saw mounted on a shaft driven by the pile-driver engine. A saw, shaft, pulleys and belt were bought for this purpose and rigged up by the pile-driver crew. It took them 3 days to rig the saw and cut off the 42 piles. The hole had not been dredged deep enough and the gravel that had washed in dulled the teeth of the saw requiring frequent raising to resharpen it. Moreover, the engine did not have sufficient power to drive the saw at high speed, and the piles were as much chewed off as sawed off. All these, however, are conditions apt to be met in similar work on small jobs. The 3 days' sawing cost $64, or $1.50 per pile.

Data on Sawing Off Burlington Bridge Pier Piles.—Mr. C. Hudson gives the following description of the method used in sawing off several hundred piles for the Burlington Bridge pier, in 1868:

The piles when driven, were sawed off by machinery. On each side of the pier, and a few feet away from it, a row of piles, perhaps 6 or 8 ft. apart, was driven. These were capped, and upon the cap was placed a traveler 12 ft. wide, arranged to be moved from end to end of the pier on these caps. Upon this traveler was another and smaller one, arranged to run upon it and across the pier. This last traveler carried a vertical shaft in a properly braced frame. This shaft carried at its lower end a circular saw about 36 ins. in diameter. The shaft could be raised or lowered as required, and was driven by means of a beveled gear from a horizontal shaft on the little traveler. A long belt extended the whole length of the large traveler, around a pulley on this horizontal shaft, and another guide pulley, so arranged that the shaft was turned regardless of the position of the little traveler. An engine on a boat alongside the pier was the motive power.

The little traveler was fed across the pier by means of a set of small blocks on each side, and a line which ran around a wheel shaft like a ship's steering wheel. By this means the traveler could be moved either way, and could thus cut off a row of piles running one way, and then, by feeding back cut the next row, the large traveler having been moved back to reach it. In this way 12 or 15 piles were cut off per hour. The efficiency of the saw under water is, of course, very much less than in the air.

Cost of Pulling and Driving Piles for a Guard Pier.—The pile protection, or guard pier, of an old draw bridge, across a tributary of the Hudson River, was removed and new piles were driven. I sublet the work, and the following are the actual costs to the subcontractor:

The number of piles pulled was 200, and the time required was 10 days. A scow pile driver was used, the engine being a friction-clutch machine, and the hammer weighing 2,200 lbs. To pull the

piles, a pair of heavy triple-sheave blocks were used. The pulling was easy, the piles being only 10 to 15 ft. in rather soft ground. The daily (10-hr.) cost of operating the scow was as follows:

	Per day.
1 captain of driver	$ 2.50
1 engineman	2.00
3 men, at $1.80	5.40
½ ton coal, at $3	1.00
Rent of driver	5.00
Total, 20 piles pulled, at 80 cts.	$15.90

This same crew then drove 200 new piles in 20 days, or 10 piles per day, at a cost of $1.60 per pile. The piles were driven 15 to 20 ft., and were 30 to 35 ft. long after cutting off. The slowness of the driving was largely due to delays caused by navigation at high tide, the channel being so narrow that the driver had to drop down with the tide to make way for boats to pass, and then pull back against the tide. On some days the driver was interrupted in this way as many as 8 times.

After the piles were driven and cut off, a 6 x 12-in. wale piece was bolted on each side of the piles, entirely around the guard pier, the wale piece being 1 ft. below the top of the piles. Another (but single) wale piece was bolted to the piles, on the outside, at low water. To these wale pieces, 3 x 12-in. sheeting planks were spiked upright; and two more lines of 6 x 12-in. walings were bolted through the sheeting and inside wale pieces, to hold the sheeting in place. The 1-in. bolts were countersunk. The timber for the wale pieces was yellow pine in 16-ft. lengths, and had to be scarfed with a 12-in. ship lap on each end, and drift bolted twice. This scarfing was expensive work, beside causing a 6% loss of timber at the scarfs. If longer lengths than 16 ft. had been used, the cost of labor and the waste of timber would have been less. Beside the wale pieces and sheeting, there were 6 x 12-in. timbers bolted on each side of every fifth bent of piles; and the center piles of the bent were capped, lengthwise of the guard pier, with a 12 x 12-in. cap. There were nearly 30,000 ft. B. M. of yellow pine timber all told, which cost $23 per M delivered.

For this timberwork the same crew was used as for pile pulling and driving, except that one more timberman, at $1.80, was employed, making the daily cost $17.70. The crew averaged only 1,300 ft. B. M. per day, at a cost of nearly $14 per M for framing and placing all the timber. They were slow workers, and there were delays due to navigation.

Cost of Drawing Foundation Piles and Sheet Piles.—The following is a very brief abstract of a long illustrated article in *Engineering-Contracting*, May 8, 1907, by Mr. Charles M. Ripley, on the anchorage of the Manhattan Bridge.

Sheet Piling and Excavation.—The first work done was the excavation of the foundation pit and the driving of the foundation piles. This work was done by the J. & F. Kelley Co., as subcontractors. Sheet piling 12 ins. thick and from 20 to 30 ins. wide was driven all around the anchorage and so as to give about

4 ft. clearance on the sides and at the front and to be close against the footing masonry at the rear. It was driven by a Vulcan steam hammer. There were about 860 ft. of sheeting around the pit; the depth of the sheeting being about 25 ft. we have then some 258 M ft. B. M. of lumber in the sheeting proper not counting in waling or bracing.

Exact figures of this work are not available for publication, but the sheet piling gang working with one driver usually consisted of one foreman at $4 per day, one engineer at $4 per day and five or six dock builders receiving $2.50 per day on land and $3.50 per day on water. An 8-hr. day was worked and about twelve sheet piles were driven per machine per day. Assuming an average depth of sheeting of 25 ft. we have 300 lin. ft. of piling driven per day, or about 3,600 ft. B. M., at a labor cost of:

	Total.	Per ft.	Per M. B. M.
1 foreman at $4	$4.00	1⅓c	$1.60
1 engineer at $4	4.00	1⅓c	1.60
6 dock builders at $2.50	15.00	5c	6.00
Total	$23.00	7⅔c	$9.20

The amount of excavation inside the cofferdam was approximately 45,000 cu. yds. Taking the amount of sheeting given above as 258,000 ft. B. M., we have 174 cu. yds. of excavation for every 1,000 ft. B. M. of sheet piling, or 5.75 ft. B. M. of piling per cubic yard of excavation.

Foundation Piling.—The foundation piles were driven by a plant of four 3,500-lb. drop hammer drivers with 45-ft. leads. These machines were mounted on skids and rollers in two horizontal directions and traveled across the work, driving a strip of piling as they progressed. In addition to the drop hammer drivers there were two steam hammer drivers similarly mounted, one a 5-ton and one a 4-ton Vulcan hammer. Every sixth row of piles across the foundation pit was driven by light drop machines and was then capped with a 12 x 20-in. timber. Two of these parallel timbers formed the track for the drivers. Five rows of piles were driven from each track.

In a few cases a water jet was used to assist in the driving. Altogether 4,430 piles were driven. The piles were an average of 25 to 30 ft. long, 14 ins. in diameter at the banded end and 9 ins. in diameter at the point. The piles were driven to a refusal of a quarter of an inch and the work was so arranged that 16 piles were driven by each machine per 8-hr. day.

The gang on each machine worked an 8-hr. day and was organized as follows:

1 foreman at $4	$ 4.00
1 engineer at $4	4.00
6 laborers at $2.50	15.00
Total labor	$23.00

With each machine driving 16 piles the labor cost of driving per 25 to 30-ft. pile was $1.43 per pile. It was found in this work

that the steam hammer drivers were about 2½ times as rapid as the drop hammer drivers.

Cost of Pulling Piles.—In 1898 I had a contract for pulling piles from the bed of a river. Several hundred piles were pulled with a tripod machine, with gear wheels and triple blocks that multiplied the power 270 times, as shown on page 1047. A rope passed from the drum of the machine to a 4-hp. hoisting engine, which was thus able to pull piles driven 27 ft. into the ground. It cost $100 to make two of these machines and about $300 more for blocks and tackle and repairs.

The crew for each puller was 3 laborers, 1 boss and 1 engineman, so that the cost of wages and ¼ ton of coal was $10 per day. About 700 piles were pulled with two machines, the average depth of pile being 12 ft., although many were 25 ft. The average day's work per machine was 15 piles making the cost of labor and fuel about 70 cts. per pile. The men worked in water up to their knees and were provided with rubber boots costing $100, which, with the $400 paid for machines and repairs, made $500, or about 70 cts. more per pile, or a total of $1.40 per pile.

Chains that were wrapped around the piles in pulling were made of 1¼-in. iron, with a breaking strength of about 100,000 lbs. The strain was so great in pulling the longest piles that the chains were frequently broken.

Cost of Blasting Piles.—Several hundred piles were removed by blasting, in addition to the 700 that were pulled as above described. The piles had been cut off at the water's surface many years before, and our contract required the removal of the piles at least 4 ft. below the surface of the low water, which was equivalent to about 2 ft. below the bed of the river. Long ship augers were used to bore holes 1½ ins. in diameter and 4½ ft. deep, down the core each pile. Each laborer averaged 7 such holes bored per 10 hrs. in white oak piles, or 30 ft. per day. The cost per pile for boring and blasting was:

Labor boring, 15 cts. per hr.	$0.21
1 lb. of 70% dynamite	0.20
½ lb. of 40% dynamite	0.08
5 ft. of fuse	0.03
1 cap	0.01
Total per pile	$0.53

Each pile was loaded with two sticks of 70% dynamite and one stick of 40%. This charge would cut off the largest pile and hurl the butt 75 ft. in the air. Occasionally a very tough pile would be splintered, and had to be pulled. This added cost of pulling averaged 10 cts. more per pile, which might have been avoided by making all three sticks 70% dynamite.

Cost of Driving and Pulling Test Piles.*—A pile was driven every 50 ft. across the Hackensack River, N. J., to test the nature of the bottom. Three 90-ft. piles were used, and were pulled after driving.

**Engineering-Contracting,* July 18, 1906.

The cost of the work includes the cost of pulling as well as driving.

A scow driver was used, and the work was done at cost plus 10% for superintendence. The total number of feet penetrated by the piles was 634, or about 57½ ft. as an average of the 11 piles, 8 of which were driven to rock. The material penetrated was mud, sand and clay.

The work occupied 4½ days, of which 1¼ days were spent in transporting the driver to the site of the work and removing it from the work after completion. The cost was as follows:

Foreman, 4½ days at $4	$ 18.00
Machine men, 45 days at $3	135.00
Watchman, 4 nights at $3	12.00
Total	$165.00
Add 10 per cent for profit	16.50
Total	$181.50

This is at the rate of 30 cts. per lin. ft. of penetration for driving and pulling, but it does not include the cost of coal. Coal was probably less than ½ ton per day, or say $10 for the whole job, or less than 2 cts. per foot.

The cost of materials was as follows:

3 piles, 90 ft. long, at $25	$75.00
2 spruce piles, 52 ft. long, for use as followers, at $4	8.00
4 pile bands, at $2.50	10.00
Total	$93.00
Add 10 per cent for profit	9.30
Total	$102.30

This is equivalent to about 16 cts. per lin. foot of pile penetration. The total cost was therefore:

	Per ft. Penetration.	Per Pile.
Labor	$0.30	$16.50
Coal	.02	0.90
Materials	.16	9.30
Total	$0.48	$26.70

It will be noticed that there were 10 men and 1 foreman on the driver, which is an unusually large number; and it will also be noted that the wages paid the "machine men" were very liberal.

Since only 3¼ days were actually spent in driving, the average day's work was 3 piles driven and pulled. If an ordinary scow driver crew of 6 men at $2, and 1 man at $4, had been employed, the daily wages would have been $16. To which add $2 for coal and $6 for rental of plant, making a total of $24 per day for driving and pulling 3 test piles, or $8 per pile. Even $8 per pile would be a high cost for such work, when done by contract, if the cost of moving the driver to and from the site of the work is not included.

In view of the valuable information gained at small expense by driving test piles, it is surprising that engineers do not oftener test

the bottom of rivers in this way before drawing plans and specifications for bridge foundations, trestles, etc. When a contract has been awarded for foundations, the first thing that the contractor wants to do is to order his piles. The engineer usually refuses to furnish a bill of materials until enough piles have been driven to determine the character of the bottom. This delays the whole work, and adds materially to the contractor's expense. Moreover, it usually results in a change of specified lengths of piles, and a corresponding change in the ultimate cost of the job. The time to drive test piles is *before* the award of a contract, not *afterward.*

Cost of Driving Piles for a Shore Protection.*—Mr. Daniel J. Hauer gives the following:

The work was done by contract. The piles were for the foundation of a reinforced concrete shore protection, consisting of a pilaster spaced on 12-ft. centers and a curtain wall 6 ins. thick cast between the pilasters. Two piles were driven for each pilaster, thus making a space of 12 ft. between each set of piles. The two piles were 18 ins. center to center. This spacing is somewhat unusual, as foundation piles are seldom driven on more than 6-ft. centers, which means more piles to drive with less moving. There was nothing difficult in the driving, and no great obstacles to overcome. The work was along the shore of a tidewater bay, and except in a few places out of reach of the water. Only once for an hour or so was the work stopped by high tide. Nearly half of the work was through marshes, the rest of the driving being in stiff clay. But little cribbing had to be done, the runways being placed on blocks on the ground. Where any grading had to be done to allow the machine to be rolled ahead, it was done by other forces, and has not been included in the costs given.

The piles were not sawed off, but were driven by a follow head to the proper depth, which was 0.6 ft. below mean low water, the foundation pit having just been excavated. This was made possible by the fact that the piles were not capped, but the heads of the piles were imbedded in the concrete. The piles were delivered within easy reach of the machine by teams, this being done by another contractor.

The lengths driven varied from 10 to 30 ft., less than 5% being the last named length, while many were only 15 to 20 ft. long, more than half being but 10 ft. The average length was 12½ ft. The pile driver had leads 33 ft. high, which were bolted to a bed frame of 12 x 12-in. timbers, 5 ft. wide and 24 ft. long, upon the other end of which sat the 10-hp. hoisting engine, it being a single cylinder double drum engine with two winch heads. One drum operated the hammer fall and the other the pile hoisting line. The top of the machine was guyed by two lines run to anchors a hundred feet or more away on either side, and run through a block on the head, the other end of the line being fastened to a davit on the bed frame; this allowed of the guys being easily slackened

***Engineering-Contracting*, July 27, 1906.

or tightened. The bed frame rested on two steel rollers with holes in the end to take bars in order to roll the machine. The hammer weighed 2,000 lbs.

The machine was old and in a dilapidated condition. The fittings around the boiler and engine leaked both steam and water; the leads were badly racked; towards the end of the job the hammer frequently jumped out of them. The rollers, too, were old ones, and, besides being cracked, one had a flat side on it, so as to prevent it rolling easily. All these things materially delayed the work at times and added much to the expense of operating the driver. The condition of the boiler and the indifferent engineers who ran it, coupled with the fact that most of the work was done in the winter season, made the consumption of coal and water large.

The cost of such a plant new at the present time, including machine ropes, small tools, blocks and anchors, would not be over $1,200. Thus, if a plant rental of $5 per day was charged against the job, with work for the outfit for 100 to 120 days in the year, the entire cost of the plant would be cleared in two seasons. This charge seems to the writer to be ample, but it is customary to hire such a plant for $10 per day for short jobs.

The work will be divided into two parts, as this division will allow of a comparison of costs, driving the piles under two different foremen, also under different weather conditions; the first being done in excellent weather in the autumn, the second during the winter months. The rates of wages were also different for the men. The foreman and engineer were paid weekly and were not allowed overtime, as they lost no time. The work was seldom stopped even during stormy weather, their daily wage, prorated from the weekly rate, is used. In example No. 1 the wages paid were as follows:

Foreman	$2.50
Engine runner	2.00
Pile driver men	2.25
Laborer	1.50

In example No. 2 the daily wages were:

Foreman	$2.50
Engine runner	2.00
Pile driver men	2.00
Laborers	1.50
Cart and driver	3.00

Example I.—These piles were driven during good autumn weather. The foreman was competent and attended to his work. The machine was brought to the site of the wall on a scow, which was beached, and the engine, leads and so forth skidded off and the parts of the machine assembled. This, with the building of a camp, consumed three days, and the labor items are included in the cost of the pile driving. This foreman drove 478 piles, their average length being 15 ft. The engine used 325 lbs. of coal each day of 10 hrs., the coal costing on board of the scows $3.50 per ton. Both water and coal were brought to the work on scows, a tow costing

$15 per trip, the tug bringing a load and returning with the empties. A laborer carried the coal and water ashore from the scow in a row boat and delivered it at the engine. One man was kept at this continually, and he is listed in the cost under coal and water laborer. The monthly rental of two small scows at $50 per month is given under "scows and tugs." In listing the cost each item was kept separate and is as follows, per pile driven:

	Per pile.
Foreman	$0.151
Engineer	0.121
Pile driver men	0.830
Labor preparing piles	0.106
Coal and water laborer	0.090
Scows and tugs	0.272
Watchman	0.052
Total labor	$1.622
Coal, 325 lbs. daily	0.055
Plant (int. and deprec.)	0.320
Total	$1.997

The piles were squared on the end and prepared to be put in the leads by one man, who had no trouble in keeping this work ahead of the driving. One man attended to the water and coal, while seven men placed the piles in the leads, guided it down, placed the runways and assisted in moving the driver ahead. To accomplish this an anchor was placed in the ground ahead to act as a dead man, and with a line run from it to the winch head on the engine, the machine was pulled ahead on the rollers, the crew assisting with bars.

For the entire job an average of 17 piles were driven each day, but as three days were consumed in starting, and three additional days were used in moving the machine as explained later, the average number of piles driven for each day of driving was 21. The average length of the pile was 15 ft. They were delivered in longer lengths and sawed into two pieces of the desired length.

After working a number of days the pile driving work was stopped on account of the necessary excavation not having been made, and it was decided to move the machine back to the starting point and drive piles in the opposite direction in order to build more of the shore protection. The machine was turned around and moved in the manner as described above for a distance of 1,300 ft. Although the contractor was paid full account for this, yet the cost has been included in the figures given above. The time consumed in moving was three days, and the cost for labor, plant, coal, etc., was as follows:

Labor	$65.25
Plant rental	15.00
Coal	1.70
	$81.95

This makes a cost per pile of 17.3 cts. for moving.

During the course of the job it was necessary to move the water

and coal scows along the shore, so the water and coal tender could reach them quickly to get his supplies. The cost of this work is given under pile driver men, and was not separated from the other work.

The foreman, as stated, was a competent and intelligent one, and handled his men with some thought. He endeavored to keep up his runways and make the work light for his men, realizing that more work was accomplished in this manner.

In addition to the cost per pile, a record was kept of the cost per lineal foot of pile driven, which was:

	Per lin. ft.
Foreman	$0.010
Engineer	0.009
Pile driver men	0.057
Preparing piles	0.007
Coal and water laborer	0.006
Scows and tugs	0.020
Watchman	0.003
Total labor	$0.112
Coal, 325 lbs. daily	0.004
Plant (int. and deprec.)	0.022
Total	$0.138

Example II.—After the winter weather had set in, the necessary excavation having been made, the work was resumed. A new foreman was put in charge of the job. After moving the machine from where it was last used to the new site, the driving commenced. This move was also paid for by the railroad company. The distance was 2,500 ft. The driver was rolled 100 ft. onto an embankment, where an ox team could be brought to it, was knocked down and hauled by the yoke of oxen hitched to a timber cart. The bed frame and engine making one load, the leads another, and the hammer, ropes and small tools making a third load. The machine was then set up for work. The time consumed was five days, a day and a half of which time the ox team worked. Fifty dollars were paid for their services. The total cost of moving was:

Labor	$ 74.75
Plant rental	25.00
Coal	4.37
Ox team	50.00
	$154.12

This cost is also included in the cost of driving as given below. The average length of the piles driven was 11 ft. For the actual number of days of driving the average number driven per day was 15, while for the whole time the average number was 13. Scows were not used for coal and water, but the water was hauled from a well about half a mile distant, and the coal from another job a mile and a half away. A one-horse cart was used for this purpose, a laborer serving the engine from the supplies so hauled. The cost per pile was:

	Per pile.
Foreman	$0.194
Engineer	0.150
Pile driver men	0.864
Labor preparing piles	0.182
Coal and water laborer	0.110
Carts	0.110
Watchman	0.013
Total labor	$1.813
Coal, 500 lbs. daily	$0.070
Plant (int. and deprec.)	0.380
Total	$2.263

The cost per lineal foot of pile driven was as follows:

	Per lin. ft.
Foreman	$0.014
Engineer	0.013
Pile driver men	0.078
Labor preparing piles	0.016
Coal and water laborer	0.010
Carts	0.027
Watchman	0.005
Total labor	$0.163
Coal, 500 lbs. daily	0.005
Plant (int. and deprec.)	0.035
Total	$0.203

A comparison of the costs of these two examples of similar work is extremely interesting. The weather was favorable in the first case, but the rate of wages for pile driver men were higher and the average length of pile was longer, yet every item of cost was larger in the second example. The size of the crew was the same, but instead of one man preparing the piles two men did this work, which about doubled the cost; but this extra man made one less man working with the machine; yet that cost is increased. This and the other labor costs being enlarged is due to less work being done each day. The larger consumption of coal was due to the weather being colder and to bad firing, as will be noted later. Taking into consideration the wages the increased cost of Example II over I should have been little, if any.

The foreman in the last work was incompetent, yet a shrewd fellow. A representative of the contracting firm only visited him a few times a week, and then rarely stayed with him more than an hour. The foreman took advantage of this, and by "grand stand plays" stood well with the firm, yet shamefully neglected his work; in fact, he and his crew "soldiered."

A record was kept of the time used in doing the various kinds of work each day, and in order to illustrate how it is possible for a foreman to rob his employer this record is reproduced for several days:

December 27.—Moving runways ahead and placing them, 2 hrs.; rolling machine, 3 hrs. and 25 mins.; boiler foaming, so it would not steam, 30 mins.; driving piles, 4 hrs. and 10 mins. Total time worked, 10 hrs. and 5 mins. Crew: Foreman, engineer, 10 men,

cart and driver, 2 men preparing piles, 1 man coal and water. Foreman and 2 men went away at 8:10 to see that some timber was not afloat; came back at 9:45. (This was not necessary.)

January 8.—Moving runways and placing them, 50 mins.; rolling machine, 1 hr. and 35 mins.; driving piles, 1 hr. and 45 mins.; boiler foaming, so it would not steam, 30 mins.; out of steam through negligence of engineer, 20 mins.; 5 hrs. consumed in fixing machine, such as tightening bolts and rods, adjusting lines, most of which was unnecessary; 1 hr. should have adjusted everything that needed it. Total time worked, 10 hrs. Crew: Foreman, engineer, 11 men, cart and driver, 1 man coal and water, 2 men preparing piles.

January 15.—Waiting for steam from 7 o'clock until 10:35, 3 hrs. and 35 mins., during which time runways were placed; rolling machine, 1 hr. and 15 mins.; waiting for steam in afternoon, 30 mins.; making a follower, 1 hr. (the writer has frequently made one in 10 mins.). Total time worked, 9 hrs. and 30 mins. (30 mins. stolen by whole crew). Foreman away from work, 1 hr. Crew: Foreman, engineer, 8 men, cart and driver, 1 man on water, 2 men preparing piles for 2 hrs.

These are records picked at random, and no comment is needed regarding them, save that if accurate cost data are kept on work such rascality and incompetency could not occur. Another feature that added to the cost of Example II was that the foreman, instead of heading his machine in the direction in which he was moving, had the back end first, which prevented him from using an anchor and the winch head of his engine in moving the driver, as the other foreman did. Because he was used to moving a machine backward, owing to the fact that with such a driver the piles are frequently left standing above the surface of the ground, he could not see that when the piles were driven below the surface it was an advantage in moving ahead to have his machine with the leads in that direction. Even when he was advised to prod his machine properly he ignored the advice, and before finishing the job he had to turn the machine, as the last piles were driven so close to a high bank there was not room enough to take the driver between the piles and the bank. This turning cost $14.70 for the labor, as it consumed 6 hrs. of time.

The following shows how the time of the crew was spent for a week, the cost of each item of work being given. The week was picked at random and is in many ways representative. The total cost of labor was $148.97, divided as follows:

Fixing runways	$ 12.04
Rolling machine	18.96
Preparing piles	22.00
Serving coal and water	8.25
Hauling coal and water	16.50
Waiting for steam	8.81
Fixing machine, etc.	32.96
Driving piles	25.75
Time loafing	3.70
	$148.97

Although this work was mismanaged many lessons can be learned from it.

Cost of Driving Wakefield Sheet Piling, Chicago, Ill.*—The matter of constructing intercepting sewers for the purpose of diverting sewage into the Chicago Drainage Canal was taken up by the City of Chicago in the latter part of 1897. In August, 1899, bids were received for the construction of the south arm of that sewer system. All these bids were rejected, and in 1901 the city undertook the construction of this section of the system, employing day labor, and having all work done under the supervision of its own engineers.

We shall give a brief description of the manner and methods of driving the piling for Section G, which extended from 39th to 51st streets, and for Section H, between 51st and 63d streets. As this was the city's first experience in construction work on a large scale, it was necessary to secure an entirely new plant. Accordingly, the city built, with its own labor, a turntable drop hammer pile driver, for use on Section G. The driver had a hammer weighing 3,000 pounds, and was equipped with a 7 x 10-in. double-drum hoisting engine and a duplex steam pump for jetting. The machine cost $2,200.

As the sewer for a distance of about 2,500 ft. would be under the shoal water of the lake, and for the rest of the distance very close to the water's edge, it was necessary to use sheeting during construction, which would be practically water tight. Accordingly, Wakefield sheet piling was used, the lumber employed in its construction being 2 ins. x 12 ins. x 20 ft. Norway and Georgia pine, surfaced one side and one edge. For most of the work Southern pine was used. In practice, however, it was found that Norway pine would stand 50% more blows under a drop hammer, and, in consequence, Norway sheet piling was used where there was difficult driving.

About 12 ft. below city datum the clay line was found; immediately above this was a layer of fine blue sand mixed with short clay. This stratum when loose and wet acts very much like quicksand. Above this stratum was ordinary lake sand. The sand was very solid and compact, owing to the action of the waves of the lake, but with the exception of gravel spots the seepage was small, considering the nearness to the lake. The first sheeting was driven nearly to the bottom of the proposed excavation; but later it was found that sheeting driven 4 to 5 ft. into the clay would do sufficiently well. In order to have the sheeting left to a sufficient height above the line of the lake for protection against high water, tides, etc., 20 ft. of material was used with some exceptions.

In the bracing, 10-in. x 12-in. x 22-ft. stringers and 10-in. x 10-in. x 20-ft. braces were used. Three sets of stringers and braces were found sufficient for most of the distance. In some places, however, it was necessary on account of bad ground and swelling clay, to re-

*_Engineering-Contracting,_ March, 1906.

inforce both stringers and braces. Throughout the entire work, 2-in. Dunn screw-braces were used.

In construction, the top set of stringers and braces followed the scraping and leveling. The distance between the sheeting was 22 ft. for the 16-ft. conduit and 21¼ ft. for the 15¼-ft. conduit. A clearance of about 9 ins. between the sheeting and sewer brickwork was allowed.

As was stated previously the city had built a turntable driver for use on this section of the work. In the operation it was found practical to swing the driving apparatus about once every day. Ordinarily about 50 ft. of sheeting in each direction was driven on one side, and then 50 ft. in each direction on the other side. A water jet for jetting to the clay was used with marked success. Ordinarily, after jetting to the clay and getting the piling into position, four or five blows of the hammer were sufficient. In many cases isolated rocks, about 1½ ft. in their largest dimensions, were found from 2 ft. to 8 ft. below the surface; these were disposed of by jetting a large hole beside them. The piles were held in place during driving by a ⅝-in. buck line, attached to the front drum of the hoisting engine, and leading through the sheaves attached to the pile driver and sheeting in place, to and around the pile to be driven. In making each Wakefield pile, 50-penny wire spikes were used. Half-inch carriage bolts were tried as fastenings, but it was found that the carpenters could make at least twice the number of sheet piles when 50-penny wire spikes were used. Eight to ten spikes were used per pile. The pile-driving crew followed the gang setting the top braces; and, on straight work at least, it was planned to have a distance of about 400 ft. between the pile driver and the excavating derrick, because when the driving was too near there was trouble with seepage water from the jet.

In ordinary driving, the crew averaged about 90 pieces of sheeting for 8 hrs. This is equivalent to 45 ft. of trench sheet piled. The largest day's work was 120 pieces of sheeting placed. On some days, however, when such obstructions as piers were encountered, not more than 12 pieces of sheeting were driven; this occurred once perhaps in 300 to 400 ft.

The pile driving crew consisted of the following:

	Per day.
1 foreman, $100 per month	$ 4.16
1 engineman, $4.80 per day	4.80
1 fireman, $2.50 per day	2.50
2 carpenters, $3.60 per day	7.20
4 laborers, $2.50 per day	10.00
1 jet man, $3.00 per day	3.00
1 ladder man, $3.00 per day	3.00
2 winch men, $3.00 per day	6.00
Total	$40.66
1 ton coal	2.90
Total, 10.8 M, at $4.03	$43.56

As about 45 ft. of trench was sheet-piled per 8 hrs., the labor

cost per linear foot of sewer amounted to $0.90. The labor cost per pile was 45 cts. The bill of materials required for the average amount placed in an 8-hr. day was as follows:

10.8 M ft. B. M. 2 ins. x 12 ins. x 20 ft. timber at $22	$237.60
900 spikes, at $2.65 per 100	23.85
Total materials	$261.45

Adding the total labor cost and the total cost for material we have $305.01 as the total cost of 90 piles. From the above it will be seen that the cost per pile amounts to $3.38, of which $0.47 was for labor. The cost per 1,000 ft. B. M. of piling was about $28.

Another pile driver was built by the city for the construction of the sheet piling in that section of the intercepting sewer between 51st and 73d streets, known as Section H. This machine was also constructed on a turntable and could be swung from one side of the trench to the other. In order to secure a good foundation bearing for the runways and rollers the span of the lower bed was made 34 ft. The driver was equipped with a 7 x 10-in. double-drum engine, had 40 ft. leads and a 2,500-lb hammer. A jet pump, with water tank, 20 ft. jet tube and other appliances were also among the equipment.

As in the first case, the sheeting was of the ordinary Wakefield pattern, made up of 2-in. x 12-in. plank, fastened together, however, by 60-penny spikes. The method of driving this sheeting was as follows: The top set of stringers and braces were put in place for 100 ft. to 200 ft. in advance, and about 18 ins. below the surface of the street; a second set of stringers, parallel with the street, made up of 4-in. x 12-in. plank, was put in about 5 ins. outside of the main stringers and on the same level as those inside, for the purpose of keeping the sheeting in line. All braces and timbers were then covered with sand to prevent their being washed out by the water jet. The sheeting used was 18 ft., 20 ft., 22 ft. and 24 ft. long, depending on the depth of the clay. The top of the sheeting was driven to about 1 ft. below the street grade, and the lower end was from 2 ft. to 4 ft. in the clay. For each pile a hole was jetted to the clay line, and as soon as the jet tube was pulled out, a pile was dropped into place and pulled over the tongue of the previous pile. Excellent alignment was obtained by using a "buck line" to hold the sheeting in place while being driven. In this case the "buck line" consisted of an old cable having a loop at one end to go over the head of the pile, the other end of the cable, after passing through a couple of snatch blocks, being attached to the hoisting engine.

From 75 to 110 piles were driven in eight hours, the number depending somewhat on the character of the ground; 85 piles, however, were considered a fair day's work.

The pile driving crew and their rate of wages were as follows:

	Per day.
1 foreman, $100 per month	$ 4.16
1 jet man, $3.50 per day	3.50
2 ladder men, $2.50 per day	5.00
2 winch men, $3.00 per day	6.00
1 pile man, $2.75 per day	2.75
1 engine man, $4.80 per day	4.80
1 fireman, $2.75 per day	2.75
4 laborers, $2.50 per day	10.00
2 carpenters, $4.20 per day	8.40
Total labor per day	$47.36
1 ton coal	2.90
Total, 10.2 M, at $5	$50.26

An average of 85 piles per day were driven, which is equivalent to about 42.5 ft. of trench piled. This was at the rate of $1.11 per foot of trench for the labor cost. The labor cost per pile was 55 cents. The bill of material required for 85 ft. of piling was as follows:

10.2 M ft., 2 ins. x 12 ins. x 20 ft. timber, at $25	$255.00
850 spikes, at $2.65 per 100	22.52
Total	$277.52

From the above it will be seen that the total cost for material and driving was $3.85 for each pile, of which $0.55 was for labor. The labor cost per 1,000 ft. B. M. of piling was about $32.

Cost of Piling, Cross References.—Data on wooden piling will be found in the sections on Bridges, Railways, Sewers, etc. Data on concrete piles will be found in the section on Concrete, and on steel piles in the section on Steelwork. Consult the index under Piles.

Estimating Cost of Brush Revetment.—A very effective method of protecting the banks of a river from scour is a revetment consisting of a brush mattress on that part of the bank below extreme low water and a stone slope wall, or hand placed riprap, on the part of the bank above low water. Brush when always submerged never rots, but it is useless to carry it much above low water for it soon decays. Such brushwork is a sort of timberwork, and is therefore placed in this section of the book.

Engineers very commonly record costs of revetment in the terms of the lineal foot of bank as the unit, and, while such a unit is desirable, it is more important to reduce the costs of the mattress either to the square (100 sq. ft.) or to the square yard as the unit, for widths of mattresses vary greatly. So also should the cost of the slope wall or slope pavement be reduced to the square yard and the cubic yard measured in place in the slope wall. While data are given in the following pages as to the cost of slope wall paving, the reader should consult the section on Masonry for more complete discussion and data.

In making roughly approximate estimates it may be well to remember that rough slope wall paving seldom costs more than $2.00

per cu. yd. in place (unless stone must be brought long distances), and that a thickness of 9 ins. ordinarily suffices, thus giving a cost of 50 cts. per sq. yd., but when stone is secured near the work may not cost 30 cts. per sq. yd.

Brush mattresses can ordinarily be made and ballasted with stone for about the same cost per square yard as a rough stone slope wall, that is for 50 to 60 cts. per sq. yd., as a rather high cost, to 30 cts. per sq. yd. as a low cost attained only when brush and stone for ballast are near at hand. However, rough estimates of this kind need not be made, since the following pages give all details.

Cost of Brush Mattress and Slope Wall, Missouri River.—Mr. W. R. De Witt gives the following relative to bank revetment built in 1901, on the Missouri River, by the company forces of the Chicago & Alton Ry. In general the work was similar to that done by the Government.

The river bluffs were first graded to a slope of 1 : 2, using a water jet. A barge carrying a force pump, delivered water through a 4-in. hose at 100 lbs. per sq. in., to a 1¼ or 1½ in. nozzle. The nozzle is fitted with a lever and swivel, the pin of which is dropped into a piece of iron pipe previously driven in the ground at the top of the bank. This gives the nozzleman full control. Two laborers shift the hose. When the upper bank is graded and most of the earth thrown out into the river current, the nozzle is moved down the slope near the water surface, and the grading continued under water. The gang thus engaged is as follows:

	Per day.
1 engineman	$ 2.75
1 fireman	1.50
1 watchman	1.25
1 nozzleman	2.25
2 laborers, at $1.25	2.50
Total	$10.25
Fuel and supplies	2.25
Grand total, 800 cu. yds., at 1½ cts.	$12.50

I have assumed the individual wages, but the totals are as given by Mr. De Witt.

This crew graded 100 lin. feet. of bank about 50 ft. wide (about 800 cu. yds.) per 10 hr. day. Hence it costs $1.25 per lin. ft. for grading, which is an amazingly low cost.

The grading was followed closely by the work of weaving a willow brush mattress 86 ft. wide, 82 ft. of which were under water when it was sunk. Two barges 20 x 50 ft. were lashed end to end, and a platform and set of ways built on them. Another barge loaded with brush furnished the supply of willows. The weaving is done on the inclined ways. When the top of the ways is reached the men lift the mattress and allow the boat to drop down stream until the edge of the mattress is at the foot of the ways, and so on.

The brush is 1 to 2 ins. diam. and 15 to 25 ft. long, and is woven in and out, bundles of willows being grouped together, as

in braiding hair. The stitch is like that on a cane seated chair. The mattress is 12 ins. thick, and has a selvedge on both edges. It is strengthened and held in place by wire cables. Five pairs of ⅝-in. galv. cables run longitudinally (up and down stream), one cable of each pair under the mattress and one on top, and a single cable is run along the inshore selvedge. Similar pairs of cables are transversely at intervals 16 ft. 8 ins. (one under and one on top), and are carried up the bank and anchored to deadmen at the top. Where the longitudinal and transverse cables cross, an iron clip is used to fasten them together. The clip consists of two 7/16 in. bolts, each bent at right angles, and the threaded end of one bolt passing through a loop in the end of the other, a nut on each serving to bind them. Before fastening the clips, the slack is taken out of the cables with block and tackle.

The gang engaged in making the mattress was as follows:

1 foreman.
10 laborers skilled in weaving.
10 brush passers.
3 hand brush to brush passers.
5 laborers handling cables.
3 laborers digging and filling holes for deadmen.
1 water boy.
—
33 total.

These men averaged $1.50 each per day, or $49.50, and they built 90 lin. ft. of mattress, 86 ft. wide, or 7,740 sq. ft. per day. Hence each man averaged 235 sq. ft. per day, at a cost of $0.64 per 100 sq. ft.

A barge load of stone is swung across the mattress, and stones weighing 100 to 200 lbs. are distributed over it and it is sunk. A gang of 30 men empty a barge of 150 cu. yds. of stone in 3 hrs., which sinks 200 lin. ft. of mattress. This is at the rate of 16⅔ cu. yds. of stone per man per 10 hr. day.

The inshore edge of the mattress is then filled with spalls for the distance that is 3 ft. above low water and 3 ft. below low water.

The slope wall paving is begun at a point 2 ft. above high water, and shingled down the slope, reversing the usual practice of beginning at bottom and moving up. The reason for this is that the stones thus lean away from the river, and they catch and hold all sediment as the river rises and falls. The stone is delivered in barges and wheeled in barrows up runways. The stones are so tilted that the wall is about 8 ins. thick at the top of the bank and 12 ins. at the water's edge. The paved slope is 54 ft. long, and the following gang will pave 100 lin. ft., or 5,400 sq. ft., or 600 sq. yds. per day.

	Per day.
4 pavers, at $2.50	$10.00
28 men loading and wheeling, at $1.50	42.00
Total	$52.00

The average thickness is 9 ins., hence 150 cu. yds. of stone are

laid by this gang per day, at a labor cost of 9 cts. per sq. yd., or 36 cts. per cu. yd., or $1 per 100 sq. ft. The work is very rough, no stone dressing being required, as is evident from the fact that each of the 4 pavers lays 38 cu. yds. per day.

Over the pavement is spread a 2-in. layer of spalls or crushed stone, filling all cracks to prevent washouts from surface drainage.

The following was the average cost of 8,250 lin. ft. of bank revetment.

Grading Bank:	
Labor	$0.10
Fuel, etc.	0.03
Total grading bank	$0.13
Weaving Mattress (86 ft. wide):	
0.6 cords brush at $1.75 deliv.	$1.05
8 lbs. ⅝-in. galv. cable at $0.04	0.32
½ iron clip at $0.05	0.03
0.06 deadmen (12 x 12 ins. x 4. ft.) at $1	0.06
Labor	0.55
Total weaving mattress	$2.01
Ballasting Mattress:	
0.75 cu. yds. stone at $1 deliv.	$0.75
Labor	0.07
Total ballasting mattress	$0.82
Paving Bank (54 ft. wide):	
1.5 cu. yds. stone at $1 deliv.	$1.50
Labor	0.52
Total paving bank	$2.02
Spawls on Pavement:	
0.47 cu. yds. spawls at $0.50	$0.24
Labor	0.15
Total spawls	$0.39
General Expense:	
Administration	$0.18
Care of plant	0.07
Current repairs to plant	0.02
Hire of plant	1.00
Surveys	0.05
Ice	0.03
Towage, other than brush and stone	0.08
Total general expense	$1.43
Grand total	$6.80
Add 10% for contingencies	$0.68
Total for estimate	$7.48

The plant consisted of a grading boat, a small steam boat, a mattress boat, and six barges (25 x 100 ft.) if all material is transported by steam, as was the case here.

Cost of Brush Mattress and River Bank Revetment.—Mr. Charles Le Vasseur is authority for the following: On the Mississippi River brush mattresses are now used only to protect that part of a bank that is under water, usually for a width of 250 ft. Then the

bank above water level is graded to a 1 : 1 slope by a water jet, and paved roughly with stone. The brush mattress is woven by men working on scows, the scows extending out into the river 250 ft. The scows are provided with "ways" on which the mattress rests, and, by pulling the scows along as the mattress is woven, a continuous mattress is launched into the river along the shore. The brush is made into small bundles (10 or 12 ins. diam.), or fascines bound with No. 12 wire (no brush being over 3 ins. diam.), and these are laid side by side and bound with ¼ in. steel wire, woven in and out, being drawn taut by a block and tackle. On top of the mattress are placed rows of poles, 16 ft. apart, extending up and down stream. They are lashed to the fascines with No. 7 silicon bronze wire every 5 ft., and at intermediate points with steel wire. These poles prevent the stone ballast from slipping off the mat when it is sunk on a steep slope. Rock is wheeled onto the floating mat in barrows on run planks from stone barges. The materials and labor per 100 sq. ft. of mattress are:

1.5 cords brush.

0.08 cords poles.

0.75 cu. yd. stone.

3 lbs. No. 12 galv. wire.

6 lbs. ¼ in. galv. wire strand.

4 lbs. 5/16 in. galv. wire strand.

1 lb. ½ in. galv. wire strand.

1.35 clamps, 5/16 in.

0.16 clamps, ½ in.

0.9 day labor building and sinking.

It costs about $6.80 per 100 sq. ft. of this mattress, or about $17 per lin. ft. of river bank, the mattress being 250 ft. wide. In addition it costs $1.25 per lin. ft. of bank to grade, with a hydraulic jet, the bank above the water edge. The hydraulic grader is a barge carrying a pumping plant discharging 2,000 gals. per min. under pressure of 170 lbs. (125 lbs. at the nozzle) through a 4 in. hose to (1¼ or 1½ in.) nozzles. This grading of the upper bank is not done till the mattress is sunk. Then the upper bank is paved with 0.3 cu. yd. of stone per sq. yd., at a cost of $10 per lin. ft. of bank. This makes the total cost $28.25 per lin. ft. of bank.

In grading the bank the nozzle is handled by men on top of the bank, directing the jet downward, and it cuts the slope as true as if it had been planed.

Cost of Brush Revetment Ballasted With Concrete.*—The Department of Engineering of the State of California is now using a type of flexible revetment as a protection to river banks that is quite a departure from the kind previously employed by the department. The method that was formerly used was to make a mattress of

---

**Engineering-Contracting*, Mar. 24, 1909.

brush fascines usually woven with wire or cable, and weighted down with loose rock laid on top of the mattress. If the slope of the bank below the water line, where it could not be graded, was steep, no rocks would lie in the mattress. Should erosion take place at the lower edge of the mattress, the latter would drop down, the rocks roll off and then the rush would rise with the water, be torn loose and carried away.

The type of revetment now constructed by the Department of Engineering developed from a plan originated by Nathaniel Ellery, state engineer, and was successfully used by him in bank protection work along the Eel river in Humboldt county, California.

The plan consists of a mattress composed of brush fascines 8 to 12 ins. in diameter and about 20 ft. long, bound with wire. These fascines are laid double, breaking joints, and woven over and under with three galvanized wire "strands" or cables, ¼ in. in diameter. Galvanized anchor cables, ¾ to 1 in. in diameter, are laid on the slope extending from the barge floating in the stream to upon or over the levee to a safe point where a line of concrete blocks is sunk in the soil and connected by a ½ to ¾-in. diameter galvanized cable. These anchor cables are fastened to the line attaching together the line of "deadmen," or as called by the department, anchor blocks. The anchor cables are spaced about 8 ft. centers and are attached on the water end to a line of cable passing through heavy concrete blocks made on the barge. These concrete blocks are called by the department sinker weights. After this skeleton of cable and concrete work is set and ready, the mattress is woven on top of these cables and the mattress is tied or lashed to the anchor cables beneath the mattress every 6 ft. After the mattress is woven to its desired width another cable ¾ in. in diameter and galvanized, is drawn down over the mattress directly over the anchor cable. It is fastened to the anchor cable at 6 or 8-ft. intervals through the brush. The ends of this top cable are fastened to the anchor cable on the land end by a cable clip just above the brush mat and the water end is made long enough to reach the sinker block where it is fastened. Also, just at the water edge of the mat the anchor cable and the top cable are fastened together.

Above the water the mattress is woven in place on the ground which has been prepared by grading to a uniform slope. When the water's edge is reached the weaving takes place on the cables suspended over the water by placing planks on the cables. The barge is held off shore by spars or struts which are held taut by shore lines to the barge. After the mattress is completely woven, blocks of concrete 2 or 3 ft. square and from 6 to 12 ins. thick are placed on the mattress, the size and distribution of which depends upon the figured buoyancy of the brush and the force of the current to be resisted. These blocks are molded in place on the mattress and thoroughly fastened on the top cable usually with a turn or knot of the cable firmly embedded in the concrete. When the mat is thus made ready the barge is shoved away, permitting the structure to sink and conform to the bank slope. The mattress so

made will, because of its flexibility, conform to the variations in the slope of the bank below the water where it could not be graded. Should the current cut under the edge of the mattress the weights will drop down, carrying the mattress down as the earth is washed away, and all—mattress and weighting—being secured by cables to the anchorage on shore, will continue to hang over the bank like a curtain. No weights can roll off and release the brush.

This type of revetment was used on Sherman Island in two places where the shore had been eroded by waves, and successfully protected the bank. The revetment on Sherman Island consisted of a mattress of willow brush in two sections, 176 ft. and 352 ft. in length, making a total length of 528 ft. The average width was 75 ft., and the average thickness 16 ins. The superficial area was 4,400 sq. yds. and the cubic contents 1,984 cu. yds. A total of 182 cu. yds. of concrete was used. The mattress was built from a barge, the upstream sections overlapping the previously laid section down stream. The work was done in 1908 by contract on the basis of cost plus 8 per cent. The cost of the work was as follows:

COST OF REVETMENT.

	Total.	Per cu. yd.	Per sq. yd.	Per lin. ft.
Labor	$ 224.70	$0.113	$0.051	$0.432
Brush	1,489.70	.750	.338	2.865
Cable and clips	903.94	455	.205	1.740
Equipment	96.10	.048	.022	.182
Concrete	1,313.35	.663	.301	2.535
Inspection	74.20	.037	.017	.142
Contractor's com.	215.40	.109	.049	.421
Grand total	$4,316.39	$2.175	$0.983	$8.317

In addition, grading costing $75, or $0.017 per sq. yd. of mattress, was done. This makes the total cost of the revetment $4,391.39, or $1.00 per sq. yd.

The item labor is for the mattress work and covers 715 hrs. of work, or 36 hrs. per cu. yd. of revetment, 0.16 hr. per sq. yd. and 1.35 hrs. per lin. ft. Labor was paid $2.50 per day of 8 hrs. The item brush is for 1,983.99 cu. yds. of brush at 75 cts. per cu. yd. The item cable and clips in for 37,375 ft. of cable. The item equipment covers the following items:

Barge hire and watchman	$170.00
Launch hire, 16 days	65.00
Watchman, 17 days	37.50
Moving barge, checking gravel, etc.	13.85
Material, telephone calls, etc.	10.97
Total	$297.32

This total was distributed over the revetment work proper and the concrete work. The barge hire and watchman for barge cost $10 per day and it cost $10 for tonnage to the barge. The item inspection covers surveys and inspection and was spread over the revetment work proper and the concrete.

The itemized cost of the concrete was as follows:

	Total.	Per cu. yd.
Labor, 995 hrs.	$ 311.26	$1.729
Cement, $1.27 per bbl.	305.64	1.695
Gravel, $1.25 per cu. yd.	218.00	1.211
Lumber and nails	84.07	.466
Equipment	201.22	1.118
Inspection	103.56	.575
Contractor's commission	89.60	.498
Total	$1,313.35	$7.292

Another flexible brush mattress was placed on Brannans Island, the work being done by contract on the basis of cost plus 8%.

The revetment consisted of a mattress of willow brush in three sections, 2,620 ft., 187 ft., and 175 ft., respectively; total length, 2,982 ft.; average width, 66⅓ ft.; average thickness, 14 ins.; superficial area, 21,892 sq. yds.; cubic contents, 8,586 cu. yds. This mattress was built from a barge, in sections 225 ft. in length, the up-stream sections overlapping on the previously laid section downstream. The concrete used was 700 cu. yds. The unit cost of the work was as follows:

CONCRETE.

	Total cost.	Cost per cu. yd.
Labor	$1,287.01	$1.830
Cement	1,161.29	1.659
Gravel	864.35	1.235
Lumber and nails	374.91	0.535
Equipment	1,198.25	1.711
Inspection	262.42	0.375
Commission	382.86	0.547
Total	$5,553.09	$7.901

REVETMENT.

	Total cost.	Cost per cu. yd.
Grading	$ 229.59	$0.010
Labor	1,411.33	0.064
Brush	6,440.51	0.293
Cable and clips	5,727.24	0.262
Equipment	1,281.32	0.056
Concrete	5,531.09	0.252
Inspection	262.41	0.012
Commission	1,197.89	0.055
Total	$22,081.38	$1.004

At Merkeleys, a revetment was constructed to protect a river bank which had begun to cave badly. The work was done in 1908 by contract on the basis of cost plus 8%. The revetment consisted of a mattress of willow brush in four sections, aggregating 774 ft. The average width was 40 ft. and the average thickness was 8 ins. The superficial area was 3,440 sq. yds. and the cubic contents 1,912 cu. yds. The concrete amounted to 145 cu. yds. The method of construction was the same as at Brannans Island, previously mentioned.

The unit costs of the work were as follows:

CONCRETE.

	Total.	Per cu. yd.
Labor	$ 332.17	$2.296
Cement	289.58	1.997
Rock	243.61	1.681
Lumber, etc.	213.75	1.474
Equipment	196.75	1.357
Inspection	46.75	.322
Contractor's commission	101.00	.698
Total	$1,423.61	$9.825

REVETMENT.

	Total.	Per sq. yd.
Labor	$ 246.01	$0.0715
Brush	1,434.39	.416
Cable and clips	1,025.41	.2925
Equipment	196.50	.0572
Concrete	1,423.61	.4145
Inspection	50.06	.0146
Contractor's commission	299.00	.0872
Total	$5,177.10	$1.501

A similar revetment was also constructed in connection with the work of closing a break in a levee on the Kripp Farm in the city of Sacramento. The work of closing the break in the levee was done by day labor, the state engineer's department hiring a dredge and crew at $160 per day of 22 hrs. The levee required to close the break was 1,600 ft. long, 24 ft. maximum height and 16 ft. wide on top, containing 102,489 cu. yds. of earth. The actual cost of building the levee, including superintendence and inspection was $5,667.64, or 5½ cts. per cu. yd.

The revetment was built by contract on the basis of cost plus 10%. It consisted of a mattress of willow brush, 710 ft. long, 40 ft. wide and 12 ins. thick. The superficial area was 3,400 sq. yds. and the cubic content was 1,172 cu. yds. The concrete used amounted to 100 cu. yds. The mattress was made on the bank and in place. The unit costs of the work were as follows:

CONCRETE.

	Total cost.	Cost per cu. yd.
Labor	$247.06	$2.47
Cement	163.79	$1.64
Gravel	135.00	1.35
Lumber	41.53	0.41
Equipment	139.28	1.39
Inspection	25.00	0.25
Commission	72.66	0.73
Total	$824.32	$8.24

REVETMENT.

	Total cost.	Cost per sq. yd.
Labor	$ 174.18	$0.042
Brush	921.05	0.272
Cable and clips	548.92	0.162
Concrete	824.32	0.269
Inspection	148.00	0.044
Commission	184.48	0.054
Total	$2,778.95	$0.843

Cost of Brush Mattresses.*—Maj. D. Fitch gives the following: Brush mattresses, riprapped with stone, were used to protect the bank of the Upper White River, Arkansas, in connection with building a timber crib dam. The cost of riprapping is given in detail in the section on Masonry, and the cost of the timber crib is given elsewhere in this section. Work was done by Government forces, laborers receiving $1.50 per 8-hr. day.

The following was the cost of the protection mattress work:

PROTECTION MATTRESS (293 SQ. YDS.).

	Unit cost.	Total.	Per sq. yd.
Riprap, 320 cu. yds.	$0.74	$237	$0.808
Inspection of riprap, 320 cu. yds.	.008	3	.010
Cutting and hauling brush, 169 cords.	1.669	282	.962
Weaving and sinking, 293 sq. yds.	1.344	394	1.344
Total		$916	$3.124

The total labor time for cutting and hauling 160 cords of brush was 150 days, the work done per man per day being 1.09 cords; the total labor time for weaving and sinking 293 sq. yds. of mattress was 223 days, the work done per man per day being 1.31 sq. yds.

450 Ft. Bank Revetment.—This work included the construction of 200 brush mats, the grading of the bank and paving it with riprap, the cost of the various items being as follows:

Brush Mattress:	Unit cost.	Total.	Per square.
Wire, etc.	....	$108	$0.54
Riprap, 336 cu. yds.	$.74	248	1.48
Cutting and loading brush, 289⅞ days.	....	531	2.60
Weaving and sinking, 213⅝ days.	....	387	1.98
Inspecting 336 cu. yds. riprap, 4 days.	....	7	....
Total, 200 squares.		$1,281	$6.40

Work done per man per day was 0.93 squares wove and sunk.

Summary for 450 ft. bank revetment:

	Total.	Unit cost.
Brush mattress, 200 squares	$1,281	$6.40
Grading bank, 450 lin. ft.	229	.51
Riprapping bank, 1,044 cu. yds.	1,000	.96

A total of 450 lin. ft. of bank was graded, the total labor time being 123 days at a cost of $229 or $0.51 per lin. ft. Each man graded 3.6 lin. ft. of bank per day.

Summarizing we get the following as the cost of the 450 ft. revetment:

Brush mattress	$1,281
Grading bank	229
Paving bank	1,000
Grand total, 450 lin. ft., at $5.58	$2,510

Cost of Mattress and Slope Wall, M., K. & T. Ry.†—Mr. R. M. Garrett is authority for the following:

The revetment put in by the Missouri, Kansas & Texas along the

*Engineering-Contracting, May 6, 1908. p. 284.

†Engineering-Contracting, March 31, 1909.

Missouri River, for shore protection, is built like that along the Missouri River, which have been put in by the Missouri River Commission, and averages about 60 ft. in width. The first work put in by this company was during 1897, and extends from the east city limits of St. Charles down the river for 9,000 ft. A rock dike was first built out into the river, and a boom made of heavy timbers was anchored to the lower side of the dike, and laid parallel with it. From this boom the mat was started, having its full width at the beginning. The mat was first woven and sunk, and then the bank was graded by hydraulic power to a slope of 2 to 1, and then paved from the top down.

In 1903, work was extended 3,000 ft. down the river, and was done in the same way as the first section, with the exception that the mat was anchored at the starting point with piles instead of the boom.

In 1906, revetment was again extended 7,200 ft. On this last section the bank was graded to a slope of 2½ to 1 in advance of weaving the mat, as considerable trouble had been experienced on former work, on account of material from the bank covering the mat, so that a connection between paving and mat could not be properly made.

Grading on this section was done with a small hoisting engine on a barge, as follows: A derrick was erected on a barge, having a boom long enough to reach the top of the bank to be graded, a No. 3 wheeler scraper pan was pulled along this boom from the barge to the top of bank, by a mule on the bank, and was held in place by two men and filled, and then dragged down the bank by the hoisting engine. The beginning of the mat was anchored to deadmen on top of the bank about 200 ft. up-stream, and weaving was begun about 100 ft. back on the old mat, so that the full width of the new mat was gotten where the unprotected bank commenced.

In 1908, 4,000 ft. of revetment was put on the north side of the river just above Boonville bridge. At Kingsbury, there is a siding on the west side of main line, and out of the south end of this track the spur was built to the river; this required a main track 6,500 ft. in length, and a spur track 900 ft. in length. Track was laid about 5 to 20 ft. from top of bank all along where revetment was to go in, so that rock could be unloaded and used with as little handling as possible. The bank was first graded to a slope of 2½ to 1 by teams; the mat was then woven and sunk, and the slope paved from bottom up. It is the description of this last section that will be given, as the only differences between this and other works are those mentioned.

The bank was about 18 ft. higher than what was taken as the average low water; the soil is mostly a very fine sand and very little gumbo; the bank was clear of timber and brush, but there were several large snags where the mat was to lie that were taken out by sawing, blowing-out and using teams and line.

Shovelers first dug along the top of the bank and shoveled down all the perpendicular and overhanging points, so as to make it safe for a mule to walk along close to the edge; then a two-mule team plowed two or three furrows as close to the edge of the bank as team could be gotten. The mules were then hitched to a "go-devil," constructed of two 2 x 10-in. plank 8 ft. long, fastened together at the front end and flared to about 4 ft. at the back end; it required one man to drive the mules and one man to weight the drag. This was then run along the back side of furrows, and the loose earth shoved toward the river. After the bank began to slope, two or three "slips" (drag scrapers) were put on, and the bank brought to the desired slope.

It will be seen that only about half of the material in slope is moved, as the excavation makes the fill and does not wash away, as it does when grading by hydraulics. It was found that with this material the filled portion was as solid as the natural surface. Grading was never carried further than 200 ft. in advance of weaving, as the barges from which the mat was being woven would protect the bank from the current for this distance.

The mat was woven 60 ft. wide with a selvage edge on the out-stream side, and sunk parallel with the shore with the inner edge about 3 ft. above the average low water. The mat was strengthened with five double rows of ⅝-in. galvanized steel cable—7 strands of No. 11 wire—laid longitudinally one above and one below, and anchored with a double row of similar cable laid transversely every 15 ft. and fastened to deadmen, buried 3 ft. deep and located 15 ft. back from the upper edge of slope. At every intersection of the longitudinal with the transverse rows, the four cables are fastened together with a ⅝-in. U clip. The transverse rows are fastened to deadmen by wrapping one cable around the deadman twice and then fastening it to the other cable with two ⅝-in. U. clip. The deadmen are pile butts about 3 ft. long, and the object in fastening the cable to them, as mentioned, is to allow the cables to slip when loaded, so that the same strain will be on both the under and upper cables. The willows were cut from bank of river about one mile above the mat, and were hauled by wagons, hauling about 1.6 cords to the load. The road was bad at times, and it required a snap team to pull out of the mudholes, but most of the time the road was in good shape. It required 0.6 cord of brush to 100 sq. ft. of mat; average thickness of mat, about 18 ins.

Weaving was started at a point at the upper end and gradually widened out to full width, anchors being placed for longitudinal cables in the top of the bank about 100 ft. above the upper end. The mat was woven with four small bags fastened together, so as to make the desired width. Fingers of skids were built on barges out of 3 x 12-in. plank, 24 ft. long, and spaced 5 ft. apart, extending from the water level on up-stream side to an elevation of 3 ft. above floor of barge at a point about 3 ft. back from down-stream side. Spools of cable were set under the down-stream ends of the fingers at the proper position for the under longitudinal cables, so

that cable would unwind as the barge was let down stream. The barge was anchored at the shore end to the track, and at the upper end to the mat that had been woven. The mat was woven on the barge as high as the fingers would permit, and cable and clip men would pull the under cables through the mat by means of an iron hook about 2 ft. long, and the top longitudinal cables were run under these, and all were fastened together with a ⅝-in. clamp. The barge was then pulled from under the mat with a team, and anchor ropes slacked just enough so that about 3 ft. of mat would be left on fingers. Top longitudinal cables were cut off of reel on shore in lengths of about 100 ft. and spliced together with a square knot on mat as the work proceeded.

The mat was sunk and held down with stone weighing from 30 to 50 lbs., an average of 1.5 cu. yds. of stone being used per 100 sq. ft. of mat. Rock for sinking was unloaded from cars onto shoulder of slope and wheeled in wheelbarrows out onto the barge, anchored lengthwise across the mat, and dumped along the edge of barge. The mat was sunk from the shore side out, so that it would settle away from shore and the transverse cables would tighten up. Sinking was kept at least 100 ft. back from weaving barge to prevent pulling the mat off of barge. When the water was higher than the proper elevation for the shore side of mat, it was sparred out, so that in sinking it would settle to its proper position.

The rock for paving the slope was unloaded from cars onto slope and rolled down to the bottom, where paving was begun. Paving is 10 ins. thick, and was paved from the bottom up, care being taken to fill all the cracks with small stone. At the upper edge of paving, spawls were piled so as to keep the surface water from washing under the paving and starting it to roll. As long as the water was low, a good connection was gotten between paving and mat, but there were parts of this work that were paved during high water, and the rock slid in afterward, making repairs necessary. The work done on the first section in 1897 is in very good shape to-day. The mat has rotted where it has been exposed to the air, but the paving is in good condition.

There have been some slides on the work done in 1906. At these places it was found that the rock was settling under the edge of the mat. These were places where the bank had washed after mat had been put in, and the mat does not lie up on the bank as it should.

Considerable trouble has been experienced on account of the eddy caused by the end of revetment. At Boonville bridge, the revetment ends at an old rock dike, and no difficulty is expected at that point, but at all of the other places it has given trouble. At the end of the work done in 1906 it is probably more noticeable. The revetment at this place was ended at a place where the bank extended out into the river 400 or 500 ft., and now the bank is 100 ft. further in than the revetment, and the revetment has been repaired

twice on account of the river washing behind the end, and allowing the rock to fall in.

The cost of the Boonville revetment (4,000 lin. ft.) is as follows: Cost per linear foot for 60-ft. mat; banks 18 ft. above low water; laborers paid $1.50 per day; foreman, $4, and teams, $3.50. This does not include interest on investment or make allowances for rainy days and moving, but is the actual cost. The contractor's profit is included in the track work only:

		Per lin. ft.
Grading bank, per lin. ft.		$0.130
Weaving mat		0.410
Sinking mat		0.110
Paving slope		0.230
Willows, including cutting, hauling and unloading, and price paid landowner		0.340
Rock, at $0.75, delivered on site (2.3 cu. yds. to the lin. ft.)		1.730
Unloading rock		0.120
Spotting cars with teams		0.004
Hauling deadmen and cable		0.018
Taking out snags		0.030
Cable and Clips:		
1,260—⅝-in. clips, at .06	$ 75.60	
746—⅜-in. clips, at .035	26.16	
107,150—⅝-in. cable, at 1.00	1,071.50	
	$1,173.26	0.300
Deadmen, 270, at 0.50 = $135.00		0.035
Total		$3.457
Track, 7,500 lin. ft.:		
Labor, grading, including contractors' profit	$1,581.90	
Labor laying	1,493.20	
Taking up	1,000.00	
	$4,075.10	
Bridge across draw	460.00	
Total track, etc.	$4,535.10	1.140
Grading spur to quarry	393.50	0.074
Total per lin. ft.		$4.671

Excluding the cost of grading the bank and the cost of the rock used in paving the bank (but including the rock used in ballasting the mattress), the cost of the mattress was as follows per square of 100 sq. ft.:

	Per square.
Willows, 0.6 cord	$0.57
Weaving mat	0.68
Sinking mat	0.18
Rock for ballast, 1½ cu. yd., at $0.75	1.13
Unloading rock, 1½ cu. yd., at $0.05	0.08
Spotting cars with team	0.03
Hauling deadmen and cable	0.03
Taking out snags	0.05
Cable and clips	0.50
Deadmen	0.06
Total	$3.31
Tracks, bridge and spur, per 1½ cu. yd. rock	0.80
Total	$4.11

The last item (tracks, bridge and spur) has been prorated to stone used on the mattress.

The slope wall on the bank required 1.4 cu. yds. per lin. ft., being 10 ins. thick and measuring 45 wide along the slope. The rock cost $0.75 per cu. yd. delivered on cars, $0.05 for unloading, and $0.16 for delivering and laying it on the slope, or a total of $0.96 per cu. yd., not including the cost of the item of tracks, bridge and spur, which amounted to $0.53 per cu. yd. of rock, there being 9,200 cu. yds. of rock in the slope wall and on the mattress. Adding this $0.53 we have a total of $1.49 per cu. yd. of slope wall, or 41½ cts. per sq. yd. 10 ins. thick.

It will be noted that the labor on the 7,500 lin. ft. of track cost as follows per lin. ft.:

	Per lin. ft.
Grading	$0.21
Laying track	0.20
Taking up track	0.14
Total	$0.55

Cost of Brush Mattresses and Dikes.*—The following data relate to levee protection work at the West Pass Levee, in Mississippi. The work was done in 1904 by Government forces, and consisted of the construction at the up-stream end of the levee of a paving covering the sloping end of the embankment and the side slopes for a distance of 100 ft. back from the end of the levee crown, together with a paving 60 ft. wide on the natural ground surface laid continuous with the paving on the slopes. The work also included the construction of paving on the down-stream end of the levee slope, beginning 100 ft. back from end of crown on lake side, extending around the sloping end, and continuing along the river slope for a distance of 555 ft., the ground surface adjacent to the paved slopes being covered with a mattress 85 ft. wide, built continuous with the paving. On the up-stream end the paving consisted of riprap laid close by hand with the larger voids clinked with spalls, except for the sloping end and the adjacent pavement, where the riprap was laid on a 3-in. layer of spalls. Around the outer edge of the paving was a trench 2½ ft. deep filled with selected heavy riprap. The paving on the downstream end was similar to that described above, but was somewhat lighter. The riprap was laid on spalls around the sloping edges, but on the earth slopes for the remaining portions. Rock for the paving on the up-stream end had been unloaded on the river bank, 1,200 ft. from the end up the levee. A portion of the rock, however, were obtained from some temporary work done the year previous. The rock for paving and ballast at the down-stream end of the levee had been unloaded at a point about 700 ft. from the work, during the preceding high water.

The mattress consisted of an upper and lower pole grillage with two layers of brush between, the grillage systems being connected

*_Engineering-Contracting,_ March 29, 1907.

by wires passing through the brush, and carried about 35 lbs. of riprap ballast to the square foot. In addition, to prevent a concentrated flow through a borrow pit in the river side, the pit was crossed by a series of pile and brush dikes having their crests on a level with the natural ground surface adjacent. The dikes were anchored to planks buried to a depth of 2½ ft. and resting on crossheads nailed to piles, which were set 6 ft. in the ground with post-hole diggers. Scour underneath the brush filling of the dikes was prevented by ballasted foot mats around the poles.

Brush for the mattress was cut at a point about four miles from the work, and was hauled by teams to the canal bank, whence it was towed by a snagboat to the levee. This barge was also used for quarters for the cutting party. Piles for the dike were obtained in a willow flat about 7,000 ft. from the work. Brush filling for the dikes was obtained from the same willow flat, 80 cords being cut from the ground adjacent to the work and 100 cords from a point about 4,000 ft. north.

The work was greatly handicapped by scarcity of labor, and, in addition, being low water while the towing was in progress, the flat fore shore of the willow flat held the barge some distance from the water's edge, necessitating a long carry and making this feature of the work slow and expensive. The lack of a proper number of barges, and of labor to load and unload them promptly, rendered it impracticable to keep the snagboat steadily employed in towing, though it was necessary to keep her constantly in commission. This still further increased the cost of brush and poles delivered at the mat.

Part of the men employed in the work were paid $1.25 per 8-hr. day, and part were subsisted laborers, receiving $30 per month and rations; this latter amounted to 32½ cts. per day, including the cook's and waiter's wages. Subsisted labor was principally used in cutting the brush for the mattress, and in loading and unloading it from wagons. About half of the loading and unloading of the barges was also done by subsisted labor. Teams including driver and wagons were secured at $3.90 per 8-hr. day for hauling at the place where the mattress brush was cut. For hauling at the down-stream end of the levee, $3.50 per day was paid for teams. Rock cost $2.18 per ton (.862 cu. yd.) delivered on river bank. The hauling for the paving at the up-stream end of the levee was done by contract at 50 cts. per ton (58 cts. per cu. yd.) and 33⅓ cts. per ton (39 cts. per cu. yd), for the long and short hauls.

The cost of stone paving at the up-stream end of the levee was as follows per square of 100 sq. ft.:

	Total.	Per square.
Superintendence	$ 40	$ 0.096
Labor, 163 days, at $1.25	204	0.492
Hauling, 219 cu. yds. rock, 3,700 ft., at $0.58	127	0.307
Hauling, 1,566 cu. yds. rock, 1,200 ft., at $0.39	605	1.461
Rock, 1,785 cu. yds., at $2.53	4,519	10.915
Total, 414 squares	$5,495	$13.271

The following is the cost of stone paving at the down-stream end of the levee for 694 squares:

	Total.	Per square.
Superintendence	$ 146	$0.21
Labor, 320 days, at $1.25	400	0.576
Hauling, 2,157 cu. yds., at $0.23	487	0.720
Rock, 2,157 cu. yds., at $2.53	5,461	7.868
Total, 694 squares	$6,494	$9.356

The cost of constructing the brush mattress at the down-stream end of the levee was as given below for 1,162 squares:

	Total.	Per square.
Superintendence	$ 182	$0.156
707 days, at $1.25	877	0.754
108 days, at $1.00	108	0.093
Subsistence, 108 days	35	0.030
Hauling, 1,743 cu. yds. rock, at $0.23	393	0.338
Rock, 1,743 cu. yds., at $2.53	4,414	3.798
Brush, at mattress, 1,139 cords, at $2.61	2,976	2.561
Poles, at mattress, 2,560, at $0.20	503	0.433
Wire, 1,100 lbs., at $0.023	26	0.022
Nails, 600 lbs., at $0.021	13	0.011
Staples, 360 lbs., at $0.022	8	0.007
Total, 1,162 squares	$9,535	$8.203

In addition a small scraper force was employed for five days in smoothing the portion of the borrow pit to be mattressed and in sloping off the bank between the pit and levee berm. Stumps left in the pit were grubbed out. The total cost of this grading and grubbing was $198 or $0.17 per mattress square.

The cost of the 1,414 lin. ft. of brush dikes is shown in the following tabulation:

	Total.	Per lin. ft.
Superintendence	$ 36.00	$0.025
Labor building dikes:		
73.1 days, at $1.25	91.40	0.065
46 1/6 days, at $1.00	46.60	0.033
Subsistence, 46 1/6 days	15.00	0.010
Piles, 480, at $0.07	33.00	0.023
Brush, 80 cords, 600 ft. haul, at $0.76	61.00	0.043
Brush, 10 cords, 4,000 ft. haul, at $0.98	98.00	0.069
Lumber, 6⅝ M ft. B. M., at $2.86	82.00	0.058
Nails, 175 lbs., at $0.021	4.00	0.000
Total, 1,414 lin. ft.	$467.00	$0.326

The approximate distribution of cost of the brush and poles used in mattress construction was as follows:

	Brush, per cord.	Poles, per pole.
Cutting privilege	$0.02	.....
Cutting	0.25	$0.02
Labor, loading and unloading, haul to bank	0.11	0.01
Team hire	0.28	0.02
Loading and unloading barges	0.68	0.06
Towing	0.44	0.03
Labor, loading and unloading, haul bank to mattress	0.12	0.01
Team hire	0.19	0.01
Superintendence	0.18	0.01
Subsistence	0.34	0.03
Total	$2.61	$0.20

The distribution of cost of hauling the rock used in mattress construction was as shown below:

	Per cu. yd.
Labor, loading and unloading wagons	$0.07
Team hire	0.14
Superintendence	0.02
Total	$0.23

Cost of Clearing Land.—The cost of clearing the margins of Indian Lake, N. Y., for 35 miles, was about $12 per acre for 1,160 acres. Men were paid $1 a day and board; and the board cost about 50 cts. a day. Foremen (1 foreman to 20 men) were paid $35 a month and board. Each acre, it was estimated, ran from 50 to 75 cords of wood. Each laborer averaged one-fifth acre cut per day, including some piling, but no burning of the timber; so that the cutting cost $7.50 per acre. There was no large merchantable timber, all having been cut down years before. The growth was mostly small pines, balsams and various hardwoods.

In the work for the filter beds at Brockton, Mass., 1894, there were 18.8 acres cleared and grubbed, of which 14.4 acres were standing pine. The trees varied from 6 to 24 ins. in diameter; and there were about 3 trees per sq. rod, or 480 per acre. When cut up, about 35 cords of wood per acre were obtained. The total cost of pulling and disposing of stumps was $112 per acre, or 23 cts. per tree. Wages of laborers were $1.50 a day.

A very common price for clearing and grubbing forest land in the eastern part of America is $50 an acre, when wages are $1.50 a day.

For contract prices see the section on Railways. Consult the index under "Clearing."

Design of Stump Pullers.—The following is a very brief abstract of two articles on grubbing stumps in *Engineering-Contracting*, March 25 and April 8, 1908. Several different types of stump pullers are illustrated in detail and their use described, but I give here only two, which are not so well known, but which I have made and used with success.

A style of stump puller, known as the sweep stump puller, is shown in Fig. 7. Its operation is simple yet very effective. One end of the sweep S rests on the ground, and the other end is mounted on a wagon wheel. The sweep is an 8 x 10-in. timber 24 ft. long, and at the free end, *B*, there is attached a single or double whiffletree, as described. The arrangement at the fixed end, *A*, is somewhat more complex and may well be described in detail. About 3 ft. from the end is an eyebolt, *I*, to which is fastened an anchoring chain attached to a convenient stump or "dead man," *P*. On each side of the eyebolt, and almost 4 ins. from it are attached hookbolts, h_1 and h_2, and still further away two similar bolts, h_3, h_4. The stump pulling wire cable is fastened to a short chain, *K*, and then carried over on *A* from *F* and attached to a pile or stump as shown. The chain *K* is hooked to the bolt h_1.

In operating it the lever is drawn in the direction of the arrow,

causing a strain on the pulling cable. The horse is driven ahead until the sweep has the position shown by the dotted lines, and when this position has been reached a short length of chain indicated by the dotted line *K* is hooked at one end to the pulling chain and at the other end to the hook bolt h_2. The horse is then turned and driven in the opposite direction, putting a further strain on the pulling chain and slacking the chain *K* so that it can be shortened and hooked up again when the horse has moved the sweep to

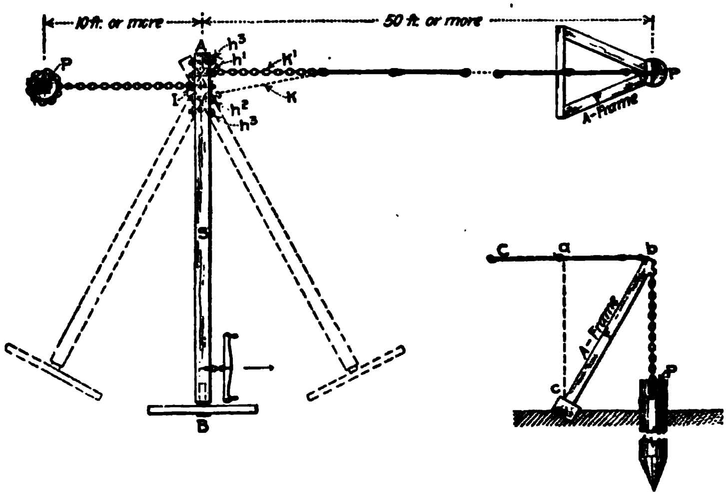


Fig. 7.—Stump Puller.

the position shown by the left hand set of dotted lines. The horse is then started on its forward trip, then back again, and so on, pulling alternately on chains *K* and K_1 and putting, ultimately, an enormous strain on the stump or pile.

An idea of the power exerted is gained from the following brief calculation. If the distance between the king bolt of the whiffletree and the bolt *I* is 20 ft., and if h_1 and h_2 are 4 ins. (⅓ ft.) from *I*, the pull of the horse is multiplied $3 \times 20 = 60$ times. A horse capable of pulling 500 lbs. would then put a strain of $500 \times 60 = 30{,}000$ lbs. on the chain *K* and K_1. Then in the triangle *a b c*, *a b* represents 30,000 lbs. and *a c* represents the pull on the stump, which must always be greater than 30,000 lbs. to an amount depending upon the inclination of the *A* frame; if the batter of the *A* frame is 1 in 3 the pull on the stump will be 40,000 lbs. As a matter of fact, one horse cannot maintain a 500-lb. pull, and a team must be used where such a pull is necessary.

Very large stumps can be pulled with this simple device and a team of horses.

From the figures given it is evident that heavy chains and cables must be used or else there will be frequent breaks.

One set up of the machine can be used to pull a large number of stumps or piles, since it is necessary to move only the comparatively light *A* frame. With a long cable, to give a good reach to the machine, there should be used take ups, else considerable time is consumed in taking up the slack of the cable. The crew to operate this style of machine consists of a foreman, three laborers and one team, the cost varying from $10 to $15 per day. This machine and the one shown in Fig. 8 were both used by one of the editors of this journal for pulling piles, the machines being adapted for either pile or stump pulling.

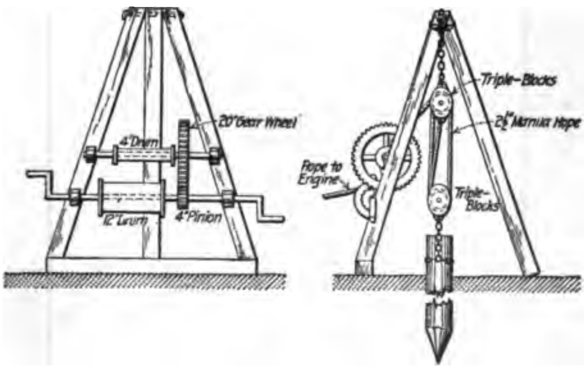


Fig. 8.—Stump Puller.

The legs of the tripod shown in Fig. 8 were 8 x 8-in. timbers, 10 ft. long. The rope is reeved through a set of triple blocks and carried to the 4-in. chain. The speed wheel and pinion are respectively 20 ins. and 4 ins. in diameter. This arrangement gives a powerful strain on the chain or cable fastened to the stump. The stumps can be pulled by hand power or horses, or a line can be run from the 12-in. drum to a small hoisting engine and the machine operated by it. This whole outfit, though, must be moved for each stump that is to be pulled.

For the cost of this tripod machine and the cost of pulling piles with it, see page 1017.

Cost of Removing Stumps in Clearing Land.*—Removing stumps by hand is a slow and costly method when the stumps are of small size and is out of the question for the large stumps of fir and other

**Engineering-Contracting,* Dec. 22, 1909.

trees up to 5 and 6 ft. in diameter. In the last condition the principal up-to-date methods are burning, blasting and pulling or some combination of these. Burning is considered the best way to remove pine stumps which have a large amount of turpentine, as this greatly assists in the process, and the long, deep roots of these trees are a great hindrancé in pulling. In regard to burning these stumps Mr. Ferris, of the Mississippi Station, says:

"The common method * * * is to dig a hole about 12 ins. deep with spade or post-hole digger on one side of the stump, as

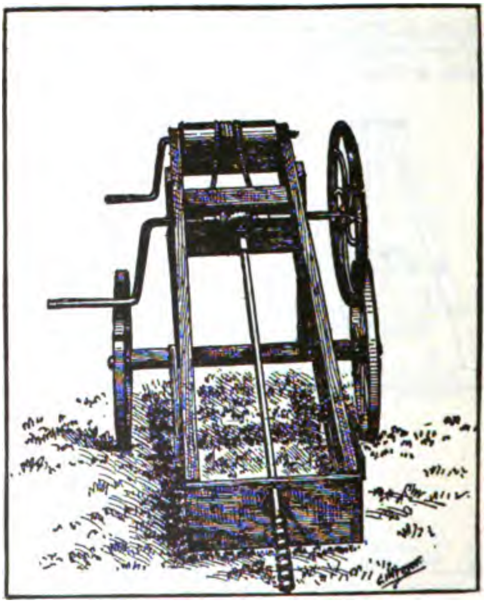


Fig. 9.—Machine for Boring Stumps.

close to it as possible, and to use this as a furnace for firing. the stump. In digging these holes it is necessary that the dirt be removed from as much of the surface of the stump as possible, so as to allow the fire to come in direct contact with the side of the stump for at least 6 ins. An ordinary turpentine dipper on a suitable handle makes one of the best implements for removing this dirt."

This is a rather slow process, but may be greatly hastened by boring a slanting hole through the stump from the opposite side to the fire hole. For boring, the Mississippi Station has used the

simple machine shown in Fig. 9, invented by J. W. Day. It is thus described:

"A 2-in. ship auger is welded onto one end of a ¾-in. iron rod 6 ft. long. Four inches from the other end of this rod a collar is welded and the end of the rod passed through an iron box fastened to a movable frame about 18 ins. square. A bevel gear is then fastened to the extreme end of this rod either by a key or set screw and works into a second gear of the same kind fastened on a horizontal shaft. This horizontal crank shaft is made of 1-in. iron rod bent at one end to form a handle, with a fly wheel fastened on the opposite end. It works through two boxes fastened to the movable frame and slides down the main frame as the auger bores into the stump. The upper end of the machine is elevated about 5 ft. and stands on two cart wheels, on which it is easily rolled from stump to stump or from field to field by a single individual. This elevation of the frame helps to brace it against the stump in boring, raises the crank shaft to a height at which it can be most easily turned, causes a slight pressure to be constantly exerted against the auger, and makes it possible to bore the hole diagonally into the stump. At the extreme upper end of the frame is a small windlass with ropes attached which is used for pulling the auger out of the stump."

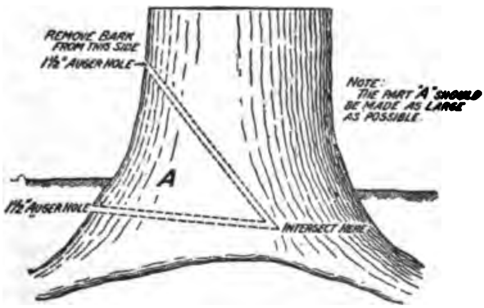


Fig. 10.—Blast Holes in Stump.

This machine was used to aid in clearing 2.3 acres of land which had been cut over about seven years before. The sapwood had decayed, but the balance of the stump above ground and all below was sound. On this plat there were 158 stumps that required boring. These averaged 13.6 ins. in diameter, and the length of hole bored averaged 19.7 ins., the total cost being less than $8 an acre, figuring labor at $1.50 per day.

For burning the large stumps of fir, etc., in the Pacific Northwest, a quicker method is used, which consists of boring two intersecting holes, as in Fig. 10, and burning by starting a fire at the inter-

section with the aid of redhot coals or a piece of iron heated to a white heat. After the part marked *A* is burned out the fire is maintained by filling the space with bark and litter. While the method first described generally results in burning the stump low enough to allow of cultivating over it in the case of pine stumps, the method used on the western trees leaves the larger stringers with their smaller roots to be pulled out by steam or puller, or "they may be entirely burned by digging away the earth and rolling a small log alongside of the root."

Other methods of burning are to split the stump with a small charge of powder and then kindle a fire in the hole thus made, and charcoaling or pitting. The latter, which consists essentially of keeping a smoldering fire around the base of the stump, is reported to be very economical for large stumps. Mr. Ferris says "removing stumps by this method [boring and burning] has been decidedly cheaper than by any other method tried, as it requires only a small expenditure for machinery, practically no repair bills, and can be operated by a single individual."

It is stated that in the section reported on by Mr. Thompson scarcely anyone undertakes to clear even a small tract without the use of powder. Powder is also used on the pine stumps of Mississippi, the common method being to bore a 1¼-in. hole from the surface of the ground diagonally downward for 10 to 20 ins. and to insert in this from ¼ to 1 lb. of dynamite. This amount will shatter the general run of pine stumps, and makes the cost of this part of the work from 5 to 20 cts. per stump. With stumps of the fir type, which do not usually root deeply, blasting is best done by placing several sticks of dynamite beneath the center on the hardpan, if not too deep, so as to cause the force of the explosion to be exerted upward. Mr. Thompson gives the following data as to size of charge under ordinary ground conditions, for shattering large stumps which are to be removed by stump pullers, blocks or teams:

Diam. of stump, ins.	18	24	30	36	48	60	72
Sticks of powder	5	7	10	20	35	50	65

The sticks are 1½ x 8 ins., weigh a little over ¾ lb. and cost from 10 cts. to 15 cts. a pound. The average cost of the removal of each stump from a tract of 120 acres containing fir stumps from 1 to 4 ft. in diameter was reported as follows:

	Cents.
Powder	49.76
Fuse	2.37
Caps	0.87
Labor	30.66
Total	83.66

If dynamite is handled with ordinary care there is but little danger attached to its use except in cold weather, when it should be kept warm, preferably at about 70° F.

After loosening and shattering stumps by blasting, it is necessary to gather them in a pile for burning. This is usually done by means of a capstan or a donkey engine. The latter is reported to have found quite general application in the Northwest. A gin pole

is set up, as shown in Fig. 11, and the stumps drawn to it. When handled to advantage this method is considered to be time-saving and cheaper than hand methods. Another type of puller is the vertical derrick, which has the advantage of applying the pull in the best direction for stumps having long tap roots, but it is objected to on account of having to be moved for each stump.

Cost of Clearing and Grubbing, Ohio.*—Mr. Julian Griggs gives the following: All trees and brush on a reservoir site, near Columbus, Ohio, were cleared and grubbed by contract in 1904-5. The work was begun June 14, 1904, and carried on continuously till Aug. 5, 1905, the season being unusually favorable. The area cleared was 255 1/2 acres, lying in a narrow river bottom 5.8 miles long. It was thickly covered with shrubs and trees—elm, locust oak, hickory, sycamore, etc. There was a rank growth of weeds, horse-cane predominating. All was grubbed except about 5 acres.

A trimming gang first cleared and grubbed the brush, cut off

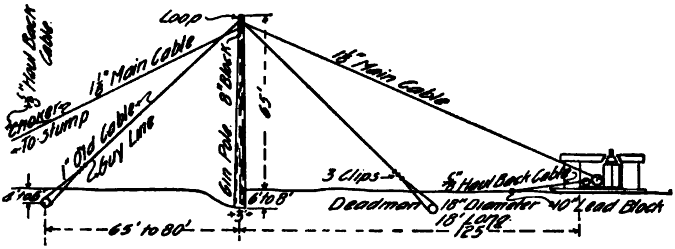


Fig. 11.—Method of Pulling and Handling Stumps.

all low limbs and all small trees, and piled the stuff ready to burn. They were followed by a pulling gang of 6 to 12 men, a team of horses and a stump puller. During the winter it was possible to burn everything as fast as cleared.

A "Hawkeye Stump Puller" was used. (This type of stump puller is illustrated and its use described in detail in *Engineering-Contracting,* March 25, 1908.) It consists of a capstan or vertical windlass (operated by a team of horses) that is mounted on a bed of two oak timbers (10 x 10-in. x 16-ft.) framed to form a cross. The drum is 2 ft. high and 13 ins. diam. The sweep (8 x 8-in.) to which the horses are fastened is 20 ft. long. Dragging from the sweep, directly back of the horses, is a stick, the end on the ground being shod with an iron point, the purpose being to take the strain off the horses when they are standing still. Two 7/8-in. wire cables, each 100 ft. long, hooks, grips, blocks, snatch cables, etc., compose the rest of the outfit. In operation, the timber bed is buried in the ground, and iron pins driven alongside the timbers into the ground,

**Engineering-Contracting,* Oct. 17, 1906.

or the timbers are loaded with stone. In pulling a tree, the snatch cable is fastened around it about 15 or 20 ft. above the ground. The cable is usually passed through a snatch block fastened to a tree near the stump puller, so as to bring the cable to a horizontal position as it winds around the drum. If the tree does not yield at first, some of the roots are cut, or a dynamite charge is exploded among the roots while the strain is kept on the cable. Stumps, of which there were many, were much harder to pull than trees, and most of them were dynamited and taken out in pieces.

The following was the cost of clearing and grubbing 255½ acres:

	Per acre.	Per cent.
Superintendent, at $4.17	$ 4.16	2.6
Timekeeper, at $1.75	1.76	1.1
Foreman, at $2.50	14.72	9.2
Carpenter, at $2.00	0.48	0.3
Dynamite men, at $1.75	3.04	1.9
Laborers, at $1.50	85.28	53.3
Single horse, at $1.50	1.28	0.8
Two-horse team, at $3.50	11.68	7.3
Total labor	$122.40	76.5
Dynamite, at 11½ cts. per lb.	30.56	19.1
Machinery and repairs	7.04	4.4
Grand total	$160.00	100.0

The work required 255 days, or an acre per day, with an average force of:

1 superintendent.
1 timekeeper.
5 foremen.
1/5 carpenter.
1¾ dynamite men.
65 laborers.
1 horse.
3½ two-horse teams.

There were 266 lbs. of dynamite used per acre.

Before the reservoir could be filled with water it had grown up with weeds, which it cost $7 more per acre to cut and burn. This was one summer's growth.

Cost of Blasting 3,500 Stumps.*—The Long Island R. R. bought a tract of land, in 1905, in Suffolk county on Long Island, in order to carry on experimental agricultural work. The tract was situated in the waste lands of the island and the first work to be done was to clear it of timber. A force of men was put to work cutting down the trees and undergrowth, and this work was followed by the stump blasting.

The blasting crew consisted of two men only, except for the three last days of the work when a third man was employed to hasten the finishing of the job. The work was done during the latter part of the summer and the fall of the year, good weather prevailing most of the time.

**Engineering-Contracting*, May 13, 1908.

One man employed was accustomed to handling explosives and had experience in blasting stumps. He was paid $3.50 for a 10-hr. day. The second man was a common laborer and was paid $1.50 per day. The third man, used for three days, also had handled explosives. He was paid $3 per day.

In all 10 acres of land were cleared. The blasting gang made the hole under the stump and charged it, setting off the charge, but the work of cleaning up after the blast was done by other men. The stumps were mainly white oak and chestnut, varying in size from 18 ins. to 7½ ft. in diameter. Many of the stumps ran from 4 to 4½ ft. in diameter. Each acre of ground was measured off and a careful record kept of the number of stumps blown on each acre.

The following table shows the number of stumps blasted and the amount of dynamite used:

Acre No.	Number Stumps.	Lbs. dynamite used per acre.	Lbs. dynamite per stump.
1	293	145½	0.50
2	310	152	0.49
3	301	169½	0.56
4	270	150¼	0.56
5	280	211¼	0.75
6	305	191½	0.62
7	285	178	0.62
8	337	188½	0.56
9	334	198½	0.59
10	797	446	0.56
Total	3,512	2,031	0.58

The soil was a light loam with sand or gravel underlying it. Naturally the amounts of dynamite used per stump varied with the size of the stump. Small stumps up to 4 ft. in diameter needed ½ lb. of dynamite. Stumps from 4 to 6 ft. in diameter needed from 1 to 3 lbs., while the largest stumps, measuring from 6 to 8 ft. in diameter needed from 3 to 4 lbs. of dynamite. The largest stump blown was a chestnut 7½ ft. in diameter which took 3½ lbs. dynamite. It will be noticed that the average per stump was not quite 0.6 lb. All the dynamite used was 40%.

In blasting the stumps the helper made a hole with an auger or bar under the stump, so the charge would be close up to the stump and near the center. The dynamiter prepared a large number of cartridges with fuse and caps in them in advance, so that when a number of holes had been made, all he had to do was to place the charge and tamp up the hole. Double tape fuse was used to put off the blast. The fuse was cut to lengths to explode the load within a given number of seconds, just enough time being allowed for a man to run to a safe distance. For most of the stumps, fuse a foot and a half in length was used, and when the end was split to allow of easy lighting, it took 30 seconds for this fuse to burn to the charge, hence this was known as a "30-second length." Care was taken to use enough dynamite to blow out the entire stump, but not to waste the explosives. Small stumps were blown out

whole, but the larger ones were split up by the blast so they could be easily handled.

The number of stumps blasted per day varied somewhat, according to the size of the stumps and the difficulties encountered. The best day's work for two men was 110 stumps, while on other days they did 97, 60, and 99, the average being 84 for two men, for the job. On one day that three men worked 160 stumps were blasted. In clearing an adjoining piece of land 1 man by himself blasted in 1 day 100 stumps, but he had prepared the charges the day previous. The cost of blasting the stumps for the 10 acres was:

	Total.	Per acre.
1 man, 40 days, at $3.50	$140.00	$14.00
1 man, 40 days, at $1.50	60.00	6.00
1 man, 3 days, at $3.00	9.00	0.90
2,031 lbs. 40% dynamite, at 15 cts.	304.65	30.46
3,600 caps, at 75 cts. per 100	27.00	2.70
7,000 ft. D. T. fuse, at 45 cts. per 100	31.50	3.15
Total	$572.15	$57.21

This gives a cost per stump of the following:

Labor	$0.059
Dynamite	0.086
Caps	0.008
Fuse	0.009
Total	$0.162

This work was done under the direction of Mr. H. B. Fullerton, special agent of the Long Island R. R. Co., to whom we are indebted for the information.

Cost of Blasting 1,100 Stumps.*—In grubbing stumps from land, one of the most economic methods is by blasting, provided care and judgment are shown in the use of explosives. The tendency seems to be to use a larger amount of explosives than is necessary. Then, too, different kinds of explosives are sometimes used in the same charge, such as dynamite and Judson powder. This should not be done. But one kind of powder should be used in a hole. For small and medium sized stumps dynamite will give the best results, but Judson powder will do efficient work on large stumps, and, at times for very large stumps, black powder is the cheapest to use.

The charge should be placed well up under the stump and as near the center of the stump as possible. A bar is generally the best tool for making the hole. When only one charge is placed under the stump it is more economical to use fuse and a cap. It is possible in stump blasting to use single tape fuse, but, if the ground is very wet, it may misfire. Under such conditions it is better to use double tape fuse. When several charges are placed under one stump, it is always advisable to use electrical exploders, so that the charges will be exploded simultaneously. For a single charge, electrical fuses are too expensive.

In the job, the cost of which we give below, dynamite was used

*Engineering-Contracting, June 3, 1908.

exclusively, and caps and fuse were used for most stumps, but electrical exploders were used on some, as several charges were placed under some of the largest stumps. There were 1,100 stumps blasted from 4 acres of land, the job being in eastern New Jersey. The trees had been cut about 2 years, and were mostly white oak and hickory. They varied in size from 4 ins. to 6 ft., the average size of the 1,100 stumps being about 15 ins. in diameter.

The dynamite used was 40 per cent. The ground was full of large boulders, and more fuse, single tape, was used than would have been required if the ground had not been full of stones. The long fuse was necessary in order to allow the men time to get away from the flying pieces of stone. Two men only were used. One man handled the dynamite and the other prepared the holes. These men did nothing towards cleaning up the stumps after they were blasted.

The cost of the labor was as follows:

Dynamiter, 19 days, at $3.50	$ 66.50
Helper, 19 days, at $1.50	28.50
Total	$ 95.00

The cost of the explosives was:

850 lbs. dynamite, at 15 cts.	$127.50
1,300 caps, at 75 cts. for 100	9.75
1,300 ft. S. T. fuse, at 45 cts. per 100	5.85
300 short electrical exploders, at 6 cts.	18.00
Total	$161.10

The total cost of the 4 acres was $256.10, giving a cost per acre of $64.02.

The cost per stump was:

Labor	$0.086
Dynamite	0.116
Caps	0.009
Fuse	0.005
Exploders	0.016
Total	$0.232

The average amount of dynamite used per stump was 0.77 lb. This is a very economical job of blasting, both as to labor, costs and explosives.

We are indebted to Mr. Oscar Kissam, of Halesite, Long Island, N. Y., for these data. The work was done under his direction and according to his methods.

Cost of Clearing and Grubbing by Blasting.*—Mr. Daniel J. Hauer is author of the following:

The work was done in 1893 in the suburb of an Eastern city. Nine acres of closely spaced trees, averaging about 20 ins. diam., were cleared. Trees ranged from 6 to 36 ins. diam. All smaller than 6 ins. was classed as brush. The trees were first cut down, and the brush and leaf wood piled and burned. The trunks were made into saw logs and cord wood. The timber was mostly oak,

*_Engineering-Contracting_, Feb. 27, 1907.

hickory and chestnut. Work was done in the spring of the year in good weather.

The tools were: 33 axes, 29 mattacks, 30 shovels, 1 hatchet, 1 band saw, 3 cross-cut saws, 2 files, 3 water buckets, 2 grindstones, 1 churn drill and 1 auger. These tools cost about $80, which could be charged at a rate of $9 per acre to the job.

Foremen were paid $2.50 per 10-hour day and laborers, mostly Italians, were paid $1.25. One foreman looked after the chopping and grubbing, consequently his salary is divided between these items, while a second foreman gave his time exclusively to the blasting.

The chopping down of 1,212 trees and the brush took about 13 days, the cost being as follows:

Foremen	$ 20.00
Laborers	149.61
Total	$169.61

This makes a cost of $18.84 per acre. For eight days, as the above work was going on, another crew of men were piling and burning brush and grubbing the small stubs and stumps. This work was done at the following cost:

Foreman	$ 10.00
Laborers	129.74
Total	$139.74

Or a cost of $15.53 per acre, and a total cost per acre for both chopping and cleaning up, of $34.37. This can be divided as follows:

Foreman	$ 3.33
Laborers	31.04

When this much of the work was done a foreman and a crew of 4 men began the blasting of stumps.

The following was the cost, 50 stumps per day:

	Per day.	Per stump.
1 foreman at $2.50	$ 2.50	$0.050
4 laborers at $1.25	5.00	0.100
200 lin. ft. double tape fuse at 50 cts. per 100 ft.	1.00	0.020
50 caps at 75 cts. per 100	0.40	0.008
52 lbs. 40% dynamite at $0.15	7.80	0.156
108½ lbs. Judson powder at $0.10	10.85	0.217
Total	$27.55	$0.551

This work took 25 days, and, as there were 134 stumps per acre on the 9 acres, the cost of blasting stumps was $73.70 per acre.

Both dynamite and Judson powder were placed in each hole.

The stumps were not so large, except in a few cases, that one charge placed under it, by churning a hole with the drill and auger beneath the stump and then loading it, did not either blow the stump out or shatter it so that the grubbers were able to handle it.

The cost of grubbing the roots after blasting was as follows:

Foreman	$ 40.00
Laborers	277.36
Total	$317.36

This makes a cost per acre of $35.26, or $0.262 per stump, which makes a total cost of $0.813 per stump for blasting and grubbing.

The grinding of the axes for chopping cost $5.87, or 65 cts. per acre, and an allowance of $9 per acre must be made for tools.

At the same time the blasting began the chopping gang began to cut the tree trunks up into cord wood and saw logs, while the cleaning gang was set to grubbing the roots and the remains of the stumps after the blasters. The saw logs and cord wood were hauled away under another contract.

The making of cord wood took eight days and cost:

Foreman	$10.00
Laborers	81.25
Total	$91.25

This was a cost of $10.14 per acre. Unfortunately the wood was not corded up before being hauled away, so no accurate record was made of the amount, but there were between 175 and 200 cords, indicating a cost of about 50 cts. per cord after the trees were cut down.

From the above we can obtain the total cost of the entire job (9 acres), which was as given below:

	Total.	Per acre.
Chopping	$ 169.61	$ 18.84
Grubbing and clearing	139.74	15.53
Making cord wood	91.25	10.14
Blasting	663.59	73.73
Grubbing after blasting	317.36	35.26
Grinding axes	5.87	0.65
Tools	81.00	9.00
Total	$1,468.42	$163.25

This is not much different from the cost of the work recorded by Mr. Julian Grigg in the following paragraphs.

Cost of Clearing and Grubbing for a Railway.*—One of the items of work to be done in grading a railroad is generally the clearing and grubbing of the land. Under some contracts and specifications this work is paid for as one item, under others as two items as clearing and as grubbing, while under other forms of contracts this work is included in that of excavation.

The method of paying for clearing by the acre as one item and grubbing as another item is to be commended. In order to do the excavation all the land must be cleared, but in addition to the area used for the cuts and embankments, the entire width of the right of way must be cleared, and overhanging trees and branches must be cut away. On the other hand there is no need of grubbing the area occupied by the embankments, nor that on the

*_Engineering-Contracting_, Dec. 25, 1907.

right of way not included in the cuts, hence there should be no reason why this area should be included in the payment. Likewise the method of doing the excavation will very materially effect the cost of the grubbing, while it does not play any part in the cost of clearing.

When steam shovels are used the grubbing cost is small, as this machine will undermine the stumps, causing them to fall into the pit, where they can be loaded onto the cars by means of chains, attached to the dipper teeth. This work retards the progress made by the shovel, but the cost of grubbing is greatly reduced, and a contractor could afford to bid a low price on the grubbing when done with a steam shovel, if it is not lumped in with the clearing or other work.

When grubbing is done in connection with rock excavation, its cost is small as the stumps are shot out with the blasting of the rock, and the only additional expense is to dispose of the stump. This will have to be done by hand and will be work that the contractor will charge for under grubbing.

When grubbing is done for scraper work the stumps and largest roots must be blasted and dug out, and the work is much more expensive than with rock excavation and steam shovel work, although a large railroad plow in loosening the ground will cut and break up many of the roots, so that they do not have to be grubbed.

The grubbing for elevating grader excavation must be done much more thoroughly, than that for scraper work. The stumps and large roots must not only be grubbed, but all the small bush stubs and roots must also be cut out. This is necessary as the grader plow will not cut these roots, as the pull on the plow is a steady one, unlike that of a breaking plow, which can be run in jerks, while the plowman can shake up the plow, which is a considerable help. In grubbing for a grader it is not advisable to blast the stumps, as this makes large deep holes, which, after rains, become full of water and soft, thus causing the traction engine and grader to mire in these holes. For this reason where there are many stumps of 6 ins. or more in size a stump puller should be used. The stump puller does its work much better than blasting, as it will not only pull up the stump, but also all the large roots and many of the small ones. Nor does it leave as large a hole as a blast does. Its work is as economical as blasting, and at times is much cheaper. The small stubs and roots must all be grubbed by hand. To do efficient work of grubbing for a grader, after the large stumps have been pulled, men should be spaced a few feet apart and the entire area gone over, the men working in rows grubbing up everything that may effect the working of the grader. This makes grader grubbing more expensive than that of any other grubbing for ordinary excavation work.

The job to be described was the clearing and grubbing on nine miles of railroad construction. Most of the line was through cultivated fields, but in 11 places varying in length from 100 to

4,600 ft. there was clearing to be done. In all there were 14¼ acres, of which 1¼ acres were over areas upon which embankments were to be made, while 13 acres were in cuts, hence there was both clearing and grubbing to do. The excavation was to be done by an elevating grader, and, as stated above, the grubbing had to be done more thoroughly than it would have been, if other methods of excavating had been employed.

The first work done was to clear the ground. Most of the brush was burned, but some of it and the logs were rolled to the edge of the right of way and piled up. The trees, of the size of 6 ins. or more in diameter, numbered about 40 to the acre; but there was a very rank undergrowth of bushes and saplings, the stumps and roots of which all had to be grubbed. The work was done by contract, and the men working upon the job were not experienced woodsmen or axemen, but were such as could be obtained at the labor market centers. Many of them were foreigners. The wages paid to the foreman was $2.50 and to the men $1.50 per ten hour day. A waterboy was paid $1.00 per day. In the clearing gang an average of 12 men were worked, some using axes and others brush hooks. The brush was piled by hand, no forks being used, and the logs, few being more than 3 ft. in diameter, were cut short and rolled by means of hand sticks. Some few were carried by the men with these sticks.

The cost per acre, there being as stated 14¼ acres, was:

	Per acre.
Foreman	$ 4.59
Men	27.10
Water boy	1.36
Total cost clearing per acre	$33.05

The grubbing was done by a gang of men averaging 15. The wages were the same. Some few of the larger stumps were blasted, and their roots afterwards grubbed. Dynamite, costing 15 cts. per lb., was used for this blasting. No separate record of the stumps that were blasted nor of the explosive used for each was kept, only the total cost of the explosives being kept, and the labor of blasting was included in with the other grubbing. About 6 stumps were blasted to the acre.

The cost per acre, there being but 13 acres to grub, was:

	Per acre.
Foreman	$ 4.54
Men	38.84
Water boy	1.81
Explosives	2.54
Total cost grubbing per acre	$47.73

The men used long cutter mattocks and short handled shovels in grubbing the stumps and roots. There is but little doubt that this cost of grubbing could have been reduced by the use of a stump

puller, but the contractor did not own one, and thought the job too small to justify purchasing such a machine.

The total cost for clearing and grubbing was as follows:

	Per acre.
Foreman	$ 8.74
Men	62.54
Water boy	3.00
Explosives	33.00
Total clearing and grubbing per acre	$76.60

The tools used for this work cost about $50, but with the exception of the brush hooks, they were all used on other work, hence to charge half their cost to this job would be sufficient. This means a charge for tools of $2 per acre, making a total of $78.60. This work was being done at the same time that grading and other construction was going on, hence the charge to be added for general expense, such as superintendence and office expenses would be small.

This clearing and grubbing was not paid for by the acre, but the work was included with the grading, and the price of excavation covered the clearing and grubbing. There was 90,000 cu. yds. of earth excavation on the 9 miles of road, hence the cost of clearing and grubbing amounted to about 1¼ ct. per cu. yd. of earth. If elevating graders had not been used, the cost with the same forces doing the work, would have been less than 1 ct. per cu. yd.

Another example of clearing and grubbing is given below. Five acres of woodland were to be cleared and grubbed of all bushes and worthless saplings, vines and briers. The undergrowth was dense. None of the trees were to be cut. The clearing was done by a contractor, but he was paid "force account," that is by the day plus a percentage for his work. The wages paid were the same as in the example just given. The brush, old logs and other debris had to be burned, and care had to be exercised that none of the trees were injured, as the woods was to be made into a park. The cost of clearing was as follows:

	Per acre.
Foreman	$ 7.25
Men	54.06
Water boy	3.00
Total	$64.31

This work was done in the fall of the year, and the weather was exceptionally good. The following spring the ground had to be thoroughly grubbed in order to plant grass seed in the woodland. This work was done with mattocks, every inch of the ground being gone over, brier roots, old stubs and all roots of bushes being dug out. There were also a few old stumps that had to be taken out, but the work was mostly the small surface roots of bushes, saplings and briers. After the ground was gone over with mattocks, steel

rakes were used to rake out the roots, and put them in piles. Wheelbarrows were then used to haul them away to a waste pile, where they were afterwards burned, when they had dried sufficiently.

This work had to be well done, or else the grass seed would not make a good sod; that an excellent sod was obtained in one season, was evidence that the work was well done. Company forces did this grubbing, the rates of wages being: Foreman $2.50 for 9 hours, and laborers $1.50 for 9 hours. The cost of the grubbing was:

	Per acre.
Foreman	$ 4.20
Men	51.30
Total	$55.50

This gives us a total cost for clearing and grubbing of $119.81 per acre. To this should be added $2.00 per acre for tools.

If this work had been done by contract, it could not have been done better, but there is little doubt, that the cost would have been less.

Cost of Transporting Logs by Driving and by Trains.*—Practically one-third of the lumber used for pulp and paper in the state of Maine comes down the Kennebec waters. The annual drive in the main river usually amounts to about 150,000,000 ft. B. M. In Water Supply and Irrigation Paper No. 198, Mr. H. K. Barrows gives some data as to the cost of driving on the above waters, the data being compiled from the reports of the Kennebec Log Driving Co., which controls the drives in the main river, the Moose River Driving Co. and the Dead River Driving Co. These companies drive the logs and apportion the cost as a tax per M. ft., this tax varying with the distance; this tax is the cost per M. ft. for logs driven the distance for which the full tax applies. In the table below the cost of log driving on Kennebec River and tributaries, 1901-1905, is given, the cost per ton mile being approximate and calculated on the basis that 1,000 ft. B. M. weighs 3,500 lbs.:

Drive.	Distance. Miles.	Average tax per M.	—Cost of driving— Per mile. Thousand.	Per ton. Mile.
Kennebec river	91	$0.41	$0.0045	$0.0026
Kennebec river	24	.12	.0050	.0028
Dead river	43	.38	.0089	.0051
Moose river	17	....	.024	.014
Moosehead lake (Moose river to lake outlet, logs towed by boat)	9	†.12	.013	.0074

The figures cover, in addition to the cost of driving itself, the

**Engineering-Contracting,* Nov. 13, 1907.

†Contract price for 10 years.

other charges arising in carrying on this work, such as costs of dams, improvement of channel, booms, etc., as well as executive charges. Many important changes have been made during the period covered by the above costs and consequently the unit costs are higher than they would have been had a longer series of years been considered. From the above table it appears that the cost of log driving per ton mile varies from about one-fourth to 1½ cts., depending on the distance driven and difficulties experienced. The average freight rate in the United States at present is about 0.8 ct. per ton mile and for the New England group of railroads 1.20 cts. per ton mile. Under exceptionally favorable circumstances rates as low as 0.2 ct. per ton mile have been granted for coal transportation from the coal fields to tide water. For the sake of comparison rates during 1906 for log transportation on the new Somerset Ry. extension are given below:

Logs shipped from Moscow to.	Average distance, miles.	Charge per ft. B. M.	Cost of transportation. Per mile. Thousand.	Per ton. Mile.
Bingham	12	$1.75	$0.146	$0.080
Solon	20	2.00	.100	.057
North Anson.....	29	*1.50	.052	.030

*This price involves reshipment as manufactured lumber on Somerset Railway.

Cost of Cordwood and Cost of a Wire Rope Tramway.—Mr. B. McIntire gives the following about a wire ropeway built by him in 1884 in Mexico. He states that when the inclination of an endless traveling ropeway is greater than about 1 in 7 it will run by gravity, the speed being controlled by a brake. A ropeway running 200 ft. per min. with buckets at intervals of 48 ft., each carrying 160 lbs., will deliver 20 tons per hr. By using two clips close together on the rope, loads of 700 lbs. per bucket may be carried. This particular ropeway was used for carrying cordwood to a mine. Its total length was 10,115 ft. between terminals, and the difference in elevation was 3,575 ft. The longest span between towers was 1,935 ft., the shortest, 104 ft.; there were 10 towers and two terminals. Hewed timbers were used for the towers, being much better than round timbers in maintenance. The rope was 13/16-in. diam., plow steel, of 300,000 lbs. strength per sq. in., bought of the California Wire Works. It was transported on 7 mules in lengths of 2,250 ft., each mule carrying a coil 321 ft. long, with a piece 10 ft. long between mules. The coils were 24 ins. diam. There were 3 men required to every 7 mules. Care must be taken to lead the mules on a steep ascent to prevent a sudden rush that may throw a mule over a precipice. The ropeway, after erection, was lubricated best by using black West Virginia oil (instead of tar), applied continuously at the rate of a drop a minute. This was vastly better than intermittent oiling.

The cost of this ropeway was as follows:

Upper terminal	$ 192.45
Lower terminal	218.00
5 trees fitted for towers	103.00
5 towers	854.25
Counterweight tower	169.00
Remodeling towers	332.00
Stretching, splicing and mounting rope, attaching clips and baskets	255.00
Total labor cost of construction	$ 2,123.70
Opening and maintaining roads	1,822.30
Ropeway, materials and transportation	15,454.00
Total cost in running order	$19,400.00

This is equivalent to about $10,000 a mile. During 9 mos. the ropeway was operated at a cost of $400 a month, and handled 660 cords per month; the items of cost being as follows for 9 mos.:

1 brakeman, at $52 per mo.	$ 468
3 men filling, at $26 per mo. each	702
1 man dumping, at $40 per mo.	360
1 man looking after line and oiling, at $26	234
Oil	117
Repairing (very heavy, $2.25 per day)	526
2 men wheeling wood away from terminal	468
2 men receiving wood from choppers and delivering it to packers	702
Total for 9 mos.	$3,577

It will be noted that the cost of labor was low, being $1 a day for common labor. The cost of cutting and delivering wood to the tramway was $2.20 per cord, and the cost of transporting by the tramway, as above given, was 60 cts. per cord (not including interest on the plant). During the previous year the cost of cutting and teaming wood had been $12 per cord. The total saving to the company, after deducting cost of tramway, was $33,500 the first year.

Cost of Planting Trees at Washington, D. C.*—During the fiscal year ending June 30, 1909, the Office of Trees and Parkings, of the Engineer Department of the District of Columbia, set out 3,988 young trees in the various streets of Washington and the District. Of this total 2,408 trees were planted in the fall season and the remainder in the spring season. The principal kinds of trees planted were elm, 626; Norway maple, 825; pin oak, 316; silver maple, 495, and sycamore, 978. The labor cost of planting the trees was as follows:

	Total.	Per tree.
Miscellaneous nursery work	$ 3,165	$0.794
Digging tree holes	9,897	2.182
Planting trees	2,394	.600
Total labor	$15,456	$3.876

*Engineering-Contracting, Dec. 29, 1909.

The cost of lumber for tree boxes and stakes, straps, strap iron and nails amounted to $1.41 per tree. This added to the labor cost makes the cost per tree $5.286. This cost is an increase of nearly 16 per cent over the cost of similar work in the previous year, the principal reason being the increased cost of skilled labor and the very large amount of nursery planting done.

Cost of Tree Planting by the Massachusetts Highway Commission.*—In 1904 the Massachusetts Highway Commission began the planting of trees along state roads. The total number of trees planted that year was 3,907, the varieties being as follows: 1,737 maples, sugar, Norway and white; 538 oak, red, scarlet, white and pin; 1,000 elm, 207 poplar and some white pine and locust. The total cost of these trees in their final location, including transplanting in a temporary nursery, care, manure, superintendence and labor, was $4,348.59, or an average of $1.14 per tree. During the fall of 1904 there was an unusually severe drought, which had a marked effect on the trees planted at the time. The total loss of trees was 15 per cent, this loss being traceable in a large degree to the dry weather. As a result greater care was taken in 1905 in preparing the ground for the reception of the trees. In 1905 the commission began placing in the state nursery all trees received from the nurserymen, so that the trees might get added development of root fibers. This made necessary two transplantings before the tree reached its final location. The cost of trees, transplanting, preparation of ground and final planting, in 1905, was $1.01 per tree. The original cost of each tree was higher in 1904, but more care was given to the preparation of the ground. The work for the year was as follows: Trees replaced, 726; new plantings, 3,239; vines planted, 300. In 1906 the systematic planting of trees along the state highways was continued, 2,511 new trees being planted that year. In addition 1,011 trees were replaced. The cost of planting the new trees in 1906, including the cost of tree and every expense connected therewith was $1.10 each. The cost of the maintenance of trees planted previous to 1906 was 16 cts. per tree, and including the cost of replaced trees 20 cts.

Cost of Digging Holes and Planting Trees and Shrubs.†—In carrying on many earthwork jobs, the engineer not only has to think and plan for the engineering features of the work, but also has to consider the artistic side, namely, the landscape features. This is rapidly becoming the case with railroad work, as the right of way of some of our larger roads is being terraced, hedges planted, and banks sodded or seeded, and the station grounds made into smooth lawns with shrubs and trees to ornament them, and well kept drives laid out through the grounds. Sewerage disposal plants, reservoirs and filter beds are likewise treated in this manner. This has made landscape architecture or engineering more prominent, and the civil engineer finds that he must give attention to these

---

**Engineering-Contracting*, April 29, 1908.
†*Engineering-Contracting*, Jan. 1, 1908.

matters. If he has much of this work to do he will call in an expert on the subject, but if the work does not warrant this expense, he will attend to the details himself.

The cost of trees can be obtained from any nursery company, but the cost of planting is more difficult to obtain.

One of the editors of this journal has done this work upon several occasions, and the following costs were kept several years ago.

The trees in the first example were known as 4 to 6 in. trees, that is, trees measuring from 4 to 6 in. in diameter. They were maples and poplars, and were bought in the early spring and "healed" in, on a nearby lot to be planted later.

Example I. In this lot there were 80 trees. The ground had been graded, to a depth of 1 to 5 feet, hence there was no soil left. For this reason it was necessary to dig a deep hole and fill it in with good soil so as to give the tree every chance of growing. The spread of the roots was about 2½ ft. on the trees, hence a hole 5 ft. in diameter and 5 ft. deep was dug. Two men working together dug the holes, digging four such holes in a day. A pick and short shovel were used by them. The dirt was thrown on the side of the hole, wheel scrapers moving it away, but this cost was not charged against the tree planting as it saved borrowing that much earth elsewhere, hence this was charged against the borrow that was being made to fill in an adjoining marsh. In each hole there was 3.6 cu. yds. of earth. The wages paid for a nine-hour day were as follows:

Foreman	$3.50
Men	1.50
4-horse team and driver	7.50
1-horse cart and driver	3.50

About six men worked in the gang, and the cost of digging the 80 holes was:

Foreman, 6½ days	$22.75
Men, 40 days	60.00
Total	$82.75

The cost per hole was:

Foreman	$0.28
Men	0.75
Total	$1.03

This gave a cost per cubic yard of earth excavated as follows:

Foreman	$0.08
Men	0.21
Total cost per cubic yard	$0.29

It must be remembered that this kind of excavation is very similar to trench work, and also to shaft sinking, as the picking is always from the top of the excavation, and in shoveling, the

shovel cannot be heaped as easily as when working against a breast.

In planting these trees soil had to be hauled several hundred feet from nearby stock piles. Wood earth was also hauled from a piece of woodland a half a mile away. Twenty-five cents a yard was paid for the privilege of getting it, and the cost of hauling and loading it is included in the cost of the tree planting. A four-horse dump wagon that carried 2 cu. yds. each trip was used for this. This wagon also hauled some loads of "mulch" from the seashore close by, a haul not exceeding 700 ft. A cart was used to haul soil and water.

The method of planting the trees consisted in filling in the bottom of the hole for about 2 ft. with soil, then using a mixture of soil and woods earth, to fill up the hole within a few inches of the top. The roots of the tree were covered with about 10 in. of this mixture of soil. The last few inches was of the "mulch" from the seashore, as this kept the ground moist and prevented it from baking. As the tree was planted, plenty of water was poured around it. The placing of rich soil around the roots and the watering allowed the fibrous roots to begin at once to take nourishment for the tree. The planting was done in the summer time, thus making it necessary to take unusual precaution that the tree should grow. After the trees were planted they were watered and sprayed each day that it did not rain.

The cost of the tree planting for these 80 trees was as follows:

Foreman, 3½ days	$12.25
Men, 20⅔ days	31.00
Teams, 4 days	30.00
Cart, 4 days	14.00
Wood's earth, 12 cu. yds., at 25c	3.00
Total	$90.25

This gives a cost per tree of the following:

Foreman	$0.15
Men	0.39
Team	0.37
Cart	0.18
Wood's earth	0.04
Total	$1.13

This makes a total cost per tree, of digging the holes and planting, of $2.16.

Example II. In this case 270 trees of about the same size were planted. The work was done in the fall of year, after the sap was down, and the ground in which they were planted had several feet of fairly good soil on it. The tree holes were made, for this reason, 5 ft. in diameter, but only 4 ft. deep. This meant the excavation of 2.9 cu. yds. for each hole. The wages paid for a 9-hour day were the same as in Example I, but, instead of working only about six men in the gang, about 24 men were worked. It

will be noticed that this materially reduced the foreman cost. The cost of digging the 270 holes was:

Foreman, 4 days	$ 14.00
Men, 95 days	142.50
Total	$156.50

The cost per hole was as follows:

Foreman	$0.05
Men	0.53
Total for hole	$0.58

The cost per cubic yard of earth excavated from the holes was:

Foreman	$0.02
Men	0.18
Total cost per cubic yard	$0.20

A comparison of this with the cost of digging the holes for the 80 trees will prove interesting. The unit cost of the foreman was reduced as explained by increasing the size of the crew of laborers, but it will be noticed that cutting off a foot of the depth (25 per cent) of the hole, decreased the cost of digging about 30 per cent. The cost of excavating per cubic yard was decreased 14 per cent. Two men working together nearly completed six 4-ft. holes in a day.

In planting the trees the same earth and soil that was dug from the hole was put back, hence the cost of planting includes the labor of back filling, the getting of the tree from the "healing in ground," the placing of it, putting some little manure around the tree after it was planted and watering while planting. No teams were necessary for this, the cost being as follows:

Foreman, 1½ days	$ 5.25
Men, 36 days	54.00
Total	$59.25

The cost per tree was:

Foreman	$0.02
Men	0.20
Total	$0.22

This makes a total cost of planting each tree of 80 cts., and illustrates how much cheaper the work can be done when the season is favorable, and the soil does not have to be hauled and prepared to place around the trees.

Example III. In this case 60 evergreen trees of various kinds from 3 ft. to 12 ft. high were planted. Earth was taken up with the roots, at the nursery where they were bought, and burlap was tied around the roots to keep this earth from falling off. As these trees were unloaded from the car, they were carried by the men directly to the place they were to be planted. Teams could not be used for this, as the lawns, which were new, would have been

ruined by the passage of wheels over them. From 2 to 4 men were needed with hand sticks to carry each tree. The holes dug were about 2½ ft. in diameter and about 18 in. deep, there being about 6.4 cu. ft. of earth excavated from each hole. The back filling was done from this material, which was piled up around the tree, leaving but little excess to be hauled away in wheelbarrows. Large pieces of canvas were laid down on the grass to hold the excavated earth, thus preventing the earth from injuring the grass. The entire lot of trees was planted in one day, and the cost consists of unloading the trees from the cars, carrying them to place, digging holes, planting trees, and cleaning up the ground and pieces of canvas afterwards. The ground was wet enough from recent rains to do away with watering the newly planted trees. The entire cost of this work was:

2 foremen, at $3.50	$ 7.00
33 men, at $1.50	49.50
Total	$56.50

The cost per tree was as follows:

Foreman	$0.115
Men	0.825
Total	$0.940

Example IV. This job consisted of planting 1,200 shrubs. About one-third of them were planted as separate shrubs or three or four plants in the same hole, the rest being planted as hedges. The holes were dug 1 ft. deep. A foreman and 3 men did the work, taking the shrubs from the "healing in ground," digging the holes, planting, back filling and watering. The wages were the same as paid in the other examples. The cost was as follows:

Foreman, 5 days	$17.50
Men, 15 days	22.50
Total	$40.00

This was a cost of a little more than 3 cents per shrub. All the work was done by day labor.

SECTION X.

BUILDINGS.

Cost of Items of Buildings by Percentages.—In any locality, if we select buildings of any given class and estimate the percentage of the total cost chargeable to each item, we find a remarkably small

	Frame Buildings.	Brick Residences.	Brick Flats and stores.	Brick Schools.	Brick Warehouses.	Machine Shops (150 x 400).
Excavation, brick and cut stone	16%	36%	38%	48%	50%	15%
Plaster	8	6	6½	6	....	....
Skylights and glass....	....	....	....	....	....	10
Millwork and glass....	21	20	17	10½	7	6
Lumber	19	12	11½	11½	18½	6½
Carpenter labor	18	10	10	10	9½	4
Hardware	3½	3	2½	2½	....	....
Tin, galv. iron and slate	2½	4½	5	3½	....	1½
Gravel roofing	....	....	1½	....	2	1½
Structural steel	....	....	5½	....	....	45½.
Steel lintels and hardware	....	....	....	....	8½	6
Plumbing and gas fitt'g	7	3	4	4	2	....
Piping for steam, water and power...	....	....	....	....	....	2
Paint	5	5½	4½	4	2½	2
Total	100%	100%	100%	100%	100%	100%

Note.—Heating is not included.

variation. For example, the hardware item in brick residences averages about 3% of the total cost of the building whether the building costs \$10,000 or \$50,000. For a \$10,000 building the hardware costs \$10,000 × 3%, or \$300. For a \$50,000 building, the hardware costs \$50,000 × 3%, or \$1,500. In making preliminary estimates of cost it is often sufficiently close to estimate one or two of the large items and calculate the rest by percentages. Every builder and architect, therefore, should analyze the actual cost of each item of a number of typical buildings, and reduce the analysis to percentages. Where foundation work is difficult and variable, it is well to exclude the foundations in forming a table of percentages, such as the one on this page. It is also well to carry the subdivisions of cost still farther; but for the purpose of example, the foregoing table serves to illustrate.

Cost of Buildings Per Cu. Ft.—In order approximately to estimate the cost of any proposed building for which plans have not yet been prepared, it is convenient to estimate the cost in cents per cubic foot. In the following examples the cubic contents are computed from the cellar floor to the roof (if the roof is flat), or (in a pitch roof) to the top of the attic walls that are finished or may be finished; but air spaces and open porches are not included. Measurements are from out to out of walls and foundations.

The following figures were compiled by Mr. James N. Brown, of St. Louis, and form part of the instructions to insurance adjusters. Prices were for the year 1902.

Country Property:	Cts. per cu. ft.
Frame dwelling, small box house, no cornice	4
Frame dwelling, shingle roof, small cornice, no sash weights, plain	5 to 6
Brick dwelling, same class	7 to 8
Frame dwelling, shingle roof, good cornice, sash weights, blinds (good house)	7 to 8
Brick dwelling, same class	9 to 10
Frame barn, shingle roof, not painted, plain finish	1½ to 2½
Frame barn, shingle roof, painted, good foundation	2½ to 3
Frame store, shingle roof, painted, plain finish	5 to 7
Brick store, shingle roof, painted, good cornice, well finished	7 to 9
Frame church or schoolhouse, ordinary	5 to 7
Brick church or schoolhouse, ordinary	8 to 10
If slate or metal roof, add ¼ ct. per cu. ft. to the above.	
City Property:	
Frame dwelling, shingle roof, pine floors and finish, no bathroom or furnace, plain finish (good house)	6 to 7
Brick dwelling, same class	8 to 9
Frame dwelling, shingle roof, hardwood floor in hall and parlor, bath, furnace and fair plumbing	8 to 9
Brick dwelling, same class	8 to 10
Frame dwelling, shingle roof, hardwood in first floor, good plumbing, furnace, artistic design, some interior ornamentation, well painted	10 to 12
Brick dwelling, good plumbing, bath, furnace, pine finish, well painted	11 to 12

Cost of Miscellaneous Buildings.—Mr. Fred T. Hodgson published the following in the Architects' and Builders' Magazine, May, 1902:

Bathhouses, complete, or for barracks, but not supplied with hot water, per cu. ft.	$ .45 to	$ .50
Or per bath	280.00 to	320.00
Baths, public, comprising swimming baths, slipper baths, laundry, caretaker's quarters, machinery, etc., complete, per cu. ft.	.30 to	.36
Breweries, complete, including buildings, cellarage, boilers, engine, machinery, coppers, liquor baths, mash tubs, coolers, refrigerator, ice storage, pumps, and all other requirements, per cu. ft.	.14 to	.20
Churches, plain, per cu. ft., from	.16 to	.22
Per sq. ft., from	4.50 to	6.50
Per sitting, from	40.00 to	55.00
Churches, ornamental, per cu. ft., from	.22 to	.39
Per sq. ft., from	7.00 to	12.50
Per sitting, from	65.00 to	120.00

Cotton mills, as generally constructed:		
Per cu. ft.	.09 to	.12
Per spindle	.22 to	.30
Cow stables, complete, with iron finishings and fittings:		
Per cu. ft.	.14 to	.16
Per sq. ft.	2.20 to	2.80
Per cow	170.00 to	190.00
Second-class stable with common fittings:		
Per cu. ft.	.11 to	.13
Per sq. ft.	1.65 to	2.00
Per cow	130.00 to	145.00
Third-class, for farm, wood fittings:		
Per cu. ft.	.07½ to	.10
Per sq. ft.	1.45 to	1.50
Per cow	90.00 to	105.00
Drill halls or sheds for infantry:		
Per cu. ft.	.11 to	.14
Per sq. ft.	1.60 to	1.70
Electric stations of power houses, buildings erected complete, exclusive of machinery and plant:		
Per cu. ft.	.14 to	.17
Flats, as constructed in New York, comprising ornamental brickwork in front, elevators, fire-resisting floors, and the whole well finished in ordinary wood throughout:		
Per cu. ft.	.28 to	.36
Hospitals, complete, including administrative buildings, etc.:		
Per cu. ft.	.20 to	.30
Per bed	1,550.00 to	2,300.00
Cottage hospitals for small towns:		
Per cu. ft.	.17 to	.22
Per bed	1,050.00 to	1,550.00
Hospitals, isolated, including all nursery buildings:		
Per cu. ft.	.17 to	.22
Per bed	1,800.00 to	2,300.00
Hotels, complete in every particular:		
First-class, per cu. ft.	.31 to	.41
Second-class, per cu. ft.	.23 to	.31
Third-class, per cu. ft.	.20 to	.24
Houses, complete, in brickwork and good substantial finishings:		
First-class—Large mansion with elaborate finish:		
Main building, 16-ft. ceiling, per cu. ft.	.30 to	.40
Per sq. ft.	5.50 to	6.50
Additions, 11-ft. ceilings, per cu. ft.	.16 to	.20
Per sq. ft.	2.50 to	3.00
Second-class—Large mansion of ordinary character:		
Main building, 14-ft. ceiling, per cu. ft.	.22 to	.30
Per sq. ft.	3.50 to	4.50
Additions, per cu. ft.	.15 to	.20
Per sq. ft.	1.65 to	2.15
Third-class—Country houses:		
Height of ceiling, 11 ft., per cu. ft.	.15 to	.20
Per sq. ft.	2.15 to	2.65
Fourth-class—Speculative buildings:		
Ceilings, 10 ft., per cu. ft.	.13 to	.15
Per sq. ft.	1.30 to	1.55
Fifth-class—Tenements and cottages to rent:		
Ceilings, 9 ft., per cu. ft.	.10 to	.12
Per sq. ft.	1.10 to	1.35

Libraries, public, complete in every particular:		
Per cu. ft.	.16 to	.22
Municipal lodging-houses for cities and large towns:		
Per cu. ft.	.15 to	.18
Per bed	300.00 to	375.00
Museums, public:		
For large cities, per cu. ft.	.22 to	.33
Towns	.19 to	.26
Music halls, complete, per head of accommodation:		
For large cities	80.00 to	130.00
For small cities and towns	40.00 to	70.00
Town halls, complete:		
Large cities, per cu. ft.	.31 to	.36
Small cities and towns	.22 to	.30
Alternative prices:		
Basement, per cu. ft.	.20 to	.24
Superstructure, per cu. ft.	.27 to	.35
Ornamental towers, per cu. ft.	.39 to	.46
Theaters, complete, per head of accommodation:		
In large cities	82.00 to	108.00
Small cities and towns	50.00 to	80.00
Per cu. ft.	.28 to	.38
Chimney shafts, plain, as for factories, etc., complete, including foundations, iron cap, etc., height measured from surface of ground to top of cap:	Per ft. in height.	
Not exceeding 100 ft. in height	$ 40.00 to	$ 46.00
100 ft. to 180 ft. high	45.00 to	52.00
180 ft. to 250 ft. high	50.00 to	56.00

Costs of Concrete Buildings.*—A common method of stating the cost of buildings for approximate estimates and comparisons is in terms of dollars per square foot of floor or cents per cubic foot of space inclosed. Either unit has been supposed to be a reliable one for approximate comparisons and both have been used frequently to prove in individual cases the economy or the high cost of construction work. In view of these facts the following comparisons made by Mr. Leonard C. Wason, president, Aberthaw Construction Co.,

TABLE I.—COST OF FIREPROOF COMPLETED CONTRACTS.

Kind of Building.	Volume in cu. ft.	Floor area in sq. ft.	Unit cost Per cu. ft.	Unit cost Per sq. ft.
Offices and stores	1,365,830	90,474	$0.133	$2.00
do.	496,780	39,840	.124	1.545
Factory	112,440	7,519	.114	1.70
do.	746,674	49,546	.060	.902
do.	312,000	24,960	.127	1.60
Garage	156,198	10,806	.085	1.23
Filter	149,250	19,208	.134	1.04
Fire station	44,265	2,982	.153	2.26
Observatory	9,734	657	.373	5.45
Filter	59,991	5,248	.333	3.82
Highest	......	......	.333	3.82
Lowest	......	......	.06	.90
Average	......	......	.138	1.72

**Engineering-Contracting*, March 10, 1909.

TABLE II.—COST OF FIREPROOF COMPLETE BUILDINGS.

Kind of Building.	Volume in cu. ft.	Floor area in sq. ft.	Unit cost— Per cu. ft.	Per sq. ft.
Storehouse	1,714,448	168,696	$0.0827	$0.84
Hospital	703,692	57,654	.0865	1.05
Office building	496,780	39,840	.124	1.545
Cold storage	1,535,000	154,000	.13	1.30
Factory	212,400	15,000	.091	1.28
do	1,327,868	106,022	.107	1.335
Storehouse	1,140,000	146,000	.0685	.575
Mfg. building	1,380,500	90,240	.067	1.01
Office	693,840	56,552	.197	2.42
Factory	105,600	8,800	.124	1.485
do	1,211,364	74,604	.0625	1.01
do	180,000	16,394	.129	1.42
Highest	......	......	.197	2.42
Lowest	......	......	.0625	.575
Average	......	......	.1088	1.27

TABLE III.—COST OF FIREPROOF BUILDINGS.

Kind of Building.	Volume in cu. ft.	Floor area in sq. ft.	Unit cost— Per cu. ft.	Per sq. ft.
Office building	441,000	35,854	$0.159	$1.97
Cold storage	1,016,400	101,640	.13	1.30
Hospital	348,320	34,832	.127	1.27
Hospital	414,732	29,838	.124	1.73
Bank	533,750	......	.123	....
Masonic	1,479,456	......	.122	....
Warehouse	259,700	24,500	.120	1.28
Garage	497,420	......	.118	....
Warehouse	2,597,000	212,000	.106	1.30
Hotel	2,116,106	......	.104	....
Hospital	485,789	38,247	.100	1.30
Office	264,687	......	.095	....
Cold storage	909,240	66,745	.091	1.24
Club	513,808	......	.085	....
Office	501,575	67,400	.084	1.12
Highest	......	......	.159	1.97
Lowest	......	......	.084	1.12
Average	......	......	.113	1.39
Per cent variation, high and low		....	53.8%	57.0%

TABLE IV.—COST OF MILL CONSTRUCTION OR SECOND-CLASS BUILDING.

Kind of Building.	Volume in cu. ft.	Floor area in sq. ft.	Unit cost— Per cu. ft.	Per sq. ft.
Mill	544,788	44,172	$0.122	$1.51
Warehouse	2,808,850	......	.12	....
Mill	1,271,300	129,920	.0891	.875
Storehouse	1,714,448	168,696	.059	.60
Mill	1,622,128	152,200	.056	.60
Mill	1,331,200	83,200	.054	.865
Mill	1,752,609	81,500	.048	1.05
Mill	2,641,000	98,059	.046	1.25
Mill	2,036,731	174,000	.046	.542
Mill	2,867,535	157,730	.045	.82
Highest	......	......	.122	1.51
Lowest	......	......	.045	.542
Average	......	......	.069	.90

Boston, Mass., will be of decided interest. In preparation for a study of the figures given it is important to note that Mr. Wason's conclusions are that, after making this comparison, he is con-

vinced that neither method is accurate enough to put much reliance on, but that the square foot method is a little safer than the other.

The comparative figures compiled by Mr. Wason are given in Tables I to IV, inclusive. In each case the total cost includes masonry and carpentry work without interior finish or decorating, plumbing and heating. The effort has been made to put the buildings upon a comparative basis as regards the amount of work done on each.

The first table consists of the total cost of actual contracts executed. The second table consists of bona fide bids on complete buildings on which Mr. Wason's company were not the lowest bidders, but where the difference was not as a rule very great. The third and fourth tables are bona fide bids on work by another contractor whose experience was similar to that of Mr. Wason's. As a rule, cubic foot measurements are given in cents only, seldom being carried to any closer subdivision. In reference to Table IV on second-class buildings, it will be noted that for the largest building a variation of 1 ct. per cu. ft., amounts to over $28,000, while the smallest one in the list amounts to only a little over $5,400. Again, on the last three items, the cubic foot price is practically identical, while the square foot measurements corresponding vary by more than 100%, with no easily apparent reason in the design.

In Table III another discrepancy is noticed. In the first and the last items, the highest and the lowest per cubic foot, as well as per square foot are on office buildings of similar type which were within one mile of each other where there is no apparent reason for such discrepancy in the design or difficulty or access in the erection of the building.

Cost of Fireproof Office Buildings.—Mr. F. J. T. Stewart gathered the following data in 1906.

The average cost of 3 office buildings in Chicago was 33 cts. per cu. ft., distributed as follows:

	Per cent.
Foundations	4.3
Steel frame	15.2
Mason work	25.5
Equipment (elevators, plumbing, lighting, heating, ventilating, etc.)	25.0
Trim and finish	30.0
Total	100.0

The average cost of 4 office buildings in Boston was 40 cts. per cu. ft., distributed as follows:

	Per cent.
Foundations	7.0
Steel frame	18.4
Mason work	35.5
Equipment	18.5
Trim and finish	20.6
Total	100.0

Comparative Cost of Wood and Steel Frame Factory Buildings.—Mr. H. G. Tyrrell gives the following, based on prices existing in Ohio in the forepart of 1905.

Slow Burning Wood Construction.—The building is 60 x 100 ft., six stories high, containing 6 floors, a roof and a cellar. The floors are designed for a load of 100 lbs. per sq. ft. The building has windows on all four sides. The walls (brick) carry the ends of the floor beams. The basement walls are 24 ins. thick. Walls of first four stories are 17 ins. thick; top two stories, 13 ins. thick. Eight tiers of columns, spaced 20 ft. apart in both directions, carry the floors and roof. The columns of the upper four stories are yellow pine, the size being 14 x 14 ins. for the lowest of these four stories. Below this, round cast iron columns are used, 11 x 1¼ in. in the first story, and 12 x 1½ ins. in the basement. All columns have cast iron bases 3 ft. square and 16 ins. high. Lengthwise through the building in the floors, run two lines of 12 x 20-in. yellow pine header beams resting on the brackets of the cast iron column caps. The cross floor beams are 8 x 16-in. yellow pine, spaced 5 ft. apart. At the columns they rest on column caps, and at intermediate points they hang from the header beams by wrought iron stirrups. In the walls the cross beams rest on cast iron wall plates, 9 x 20 x ¾ in. The floor is of ⅞-in. matched maple, laid on 1¾-in. yellow pine. The roof is similar in construction and has a tar and gravel covering.

The following estimates are for the structural part of the building only, including walls, columns, floors, roof, excavation, foundation, doors and windows, but not including partitions, stairs, elevators, plumbing, heating, lighting or wiring.

1. Excavation (cu. yds.)	1,800
2. Cellar cement floor (sq. ft.)	6,000
3. Foundation concrete (cu. yds.)	150
4. Brick (cu. ft.)	39,000
5. Windows, 4 x 7 ft.	238
6. Roofing (sq. ft.)	6,000
7. Yellow pine timber (M.)	116
8. Yellow pine flooring (M.)	73
9. Matched flooring (M.)	46
10. Iron work (tons)	46

The estimated cost of this design is $35,000, which is equivalent to 6.1 cts. per cu. ft., or 83 cts. per sq. ft. of entire floor area.

The interior framing of floors and columns (including wall plates, columns, caps and bases and stirrup irons), is 27 cts. per sq. ft. of floor area.

Fireproof Steel Construction.—This is similar in design to the above, as regards arrangement of beams and columns. Riveted steel columns are used, and the floors are framed with steel beams. The flooring between the beams is reinforced concrete.

The quantities are as before for items (1) to (6) inclusive.

The remaining items are:

7. Steel columns (tons)	105
8. Steel beams and wall plate (tons)	252
9. Concrete floor and roof (sq. ft.)	42,000

The estimated cost is $57,000, which is equivalent to 10.2 cts. per cu. ft., or $1.36 per sq. ft. of total floor area. Floors and

columns cost 75 cts. per sq. ft. of floor area, as compared with 27 cts. for the slow burning mill construction.

Cubic Foot Costs of Reinforced Concrete Buildings.*—The following costs are for buildings actually erected and they are given by Mr. Emile G. Perrot, M. Am. Soc. C. E.:

	Cents per cu. ft.
Warehouses and manufacturers	8 to 10
Stores and loft buildings	11 to 17
Miscellaneous, such as schools and hospitals	15 to 20

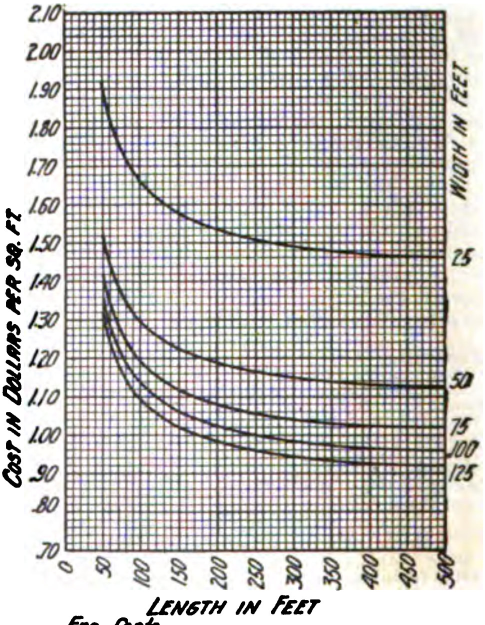


Fig. 1.

These costs include the building complete, omitting power, heat, light, elevators and decorations or furnishings.

Cost of Mill Buildings.—Mr. Charles F. Main is authority for the following data, based upon eastern prices in 1910.

It is not an uncommon thing to hear the cost of mill buildings placed from 70 cts. to $1 per sq. ft. of floor space, regardless of the size or number of stories. There is, however, a wide range of cost

*Engineering-Contracting, Jan. 27, 1909.

per square foot of floor space, depending upon the width, length, height of stories and number of stories.

Some time ago, I placed a valuation upon a portion of the property of a corporation, including some 400 or 500 buildings. In order to have a standard of cost from which to start in each case, I prepared a series of diagrams showing the approximate costs of buildings varying in length and width and from one story to six stories in height. The height of stories also was varied for different widths, being assumed 13 ft. high if 25 ft. wide, 14 ft. if 50 ft. wide, 15 ft. for 75 ft., 16 ft. for 100 ft. and over.

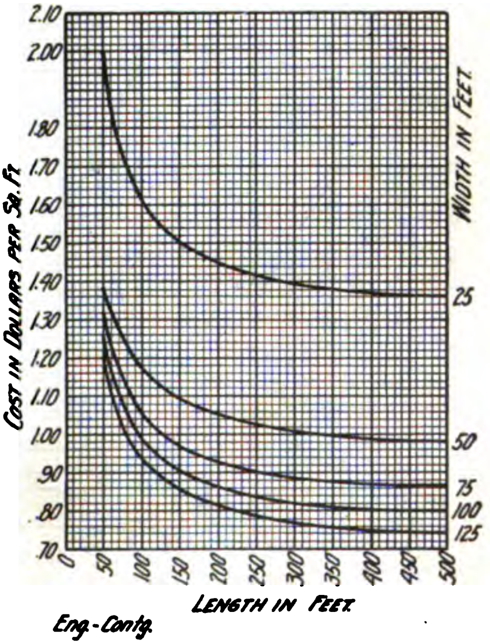


Fig. 2.

The costs used in making up the diagrams are based largely upon the actual cost of work done under average conditions of cost of materials and labor and with average soil for foundations. The costs given include plumbing, but no heating, sprinklers, or lighting. These three latter items would add roughly 10 cts. per sq. ft. of floor area.

Estimates.—The accompanying diagrams, Figs. 1 to 6, can be used to determine the probable approximate cost of proposed brick

buildings, of the type known as "slow-burning" to be used for manufacturing purposes, with a total floor load of about 75 lbs. per sq. ft. and these can be taken from the diagrams readily. The curves were derived primarily to show the estimated cost per square foot of gross floor area of brick buildings for extile mills, and to include ordinary foundations and plumbing. For example, if it is desired to know the probable cost of a mill 400 ft. long by 100 ft. wide, three stories high, refer to the curves showing the cost of three-story buildings. On the curve for buildings 100 ft.

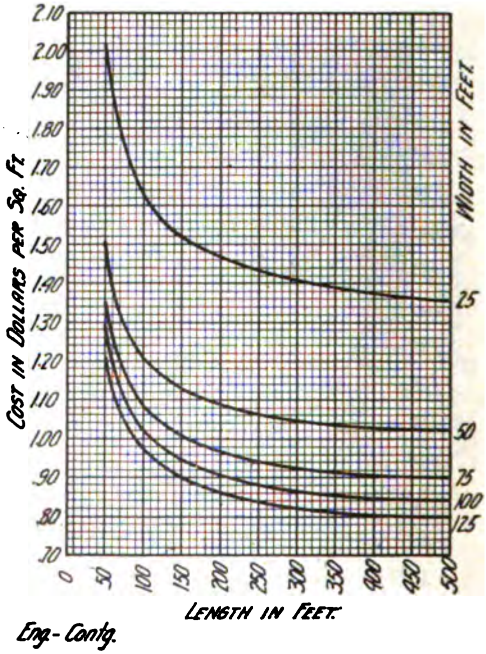


Fig. 3.

wide, find the point where the vertical line of 400 ft. in length cuts the curve, then move horizontally along this line to the left-hand vertical line, on which will be found the cost of 81 cts.

The cost given is for brick manufacturing buildings under average conditions and can be modified if necessary for the following conditions:

(a) If the soil is poor or the conditions of the site are such as to require more than the ordinary amount of foundations, the cost will be increased.

(b) If the end or a side of the building is formed by another building, the cost of one or the other will be reduced slightly.

(c) If the building is to be used for ordinary storage purposes with low stories and no top floors, the cost will be decreased from about 10% for large low buildings, to 25% for small high ones, about 20% usually being a fair allowance.

(d) If the buildings are to be used for manufacturing purposes and are to be substantially built of wood, the cost will be decreased

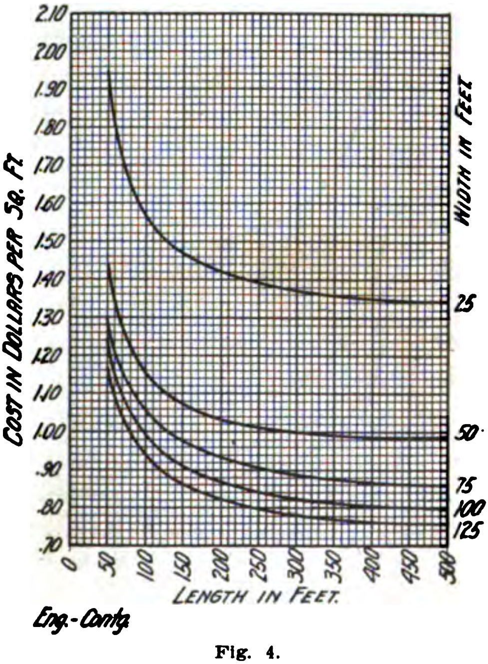


Fig. 4.

from about 6% for large one-story buildings, to 33% for high small buildings; 15% would usually be a fair allowance.

(e) If the buildings are to be used for storage with low stories and built substantially of wood, the cost will be decreased from 13% for large one-story buildings, to 50% for small high buildings; 30% would usually be a fair allowance.

(f) If the total floor loads are more than 75 lbs. per sq. ft. the cost is increased.

(g) For office buildings, the cost must be increased to cover architectural features on the outside and interior finish.

The cost of very light wooden structures is much less than the above figures would give. Table IVa shows the approximate ratio of the costs of different kinds of buildings to the cost of those shown by the curves.

Evaluations.—The diagrams can be used as a basis of valuation of different buildings.

A building, no matter how built nor how expensive it was to build, cannot be of any more value for the purpose to which it is put than a modern building properly designed for that particular purpose. The cost of such a modern building is then the limit of value of existing buildings. Existing buildings are usually of less value than new modern buildings for the reason that there has been some depreciation due to age and that the buildings are not as well suited to the business as a modern building would be.

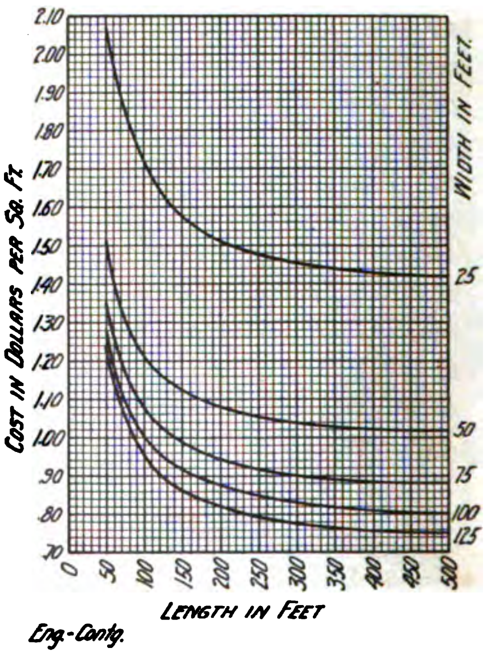


Fig. 5.

Starting with the diagrams as a base, the value can be approximately determined by making the proper deductions.

The diagrams can be used as a basis for insurance valuations after deducting about 5% for large buildings to 15% for small ones.

for the cost of foundations, as it is not customary to include the foundations in the insurable value.

Use of Tables.—Table V shows the costs which form the basis of the estimates and these unit prices can be used to compute the cost of any building not covered by the diagrams. The cost of brick walls is based on 22 bricks per cubic foot, costing $18 per thousand laid. Openings are estimated at 40 cts. per sq. ft., including windows, doors and sills.

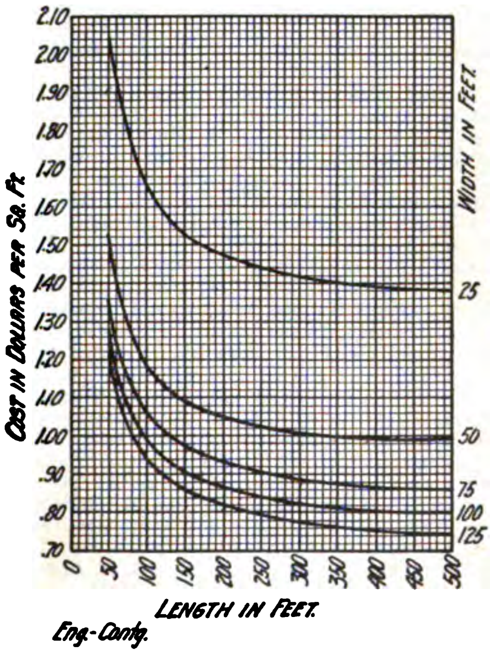


Fig. 6.

Ordinary mill floors, including timbers, planking and top floor with Southern pine timber at $40 per M. ft. B. M. and spruce planking at $30 per M., costs about 32 cts. per sq. ft., which has been used as a unit price. Ordinary mill roofs covered with tar and gravel, with lumber at the above prices, cost about 25 cts. per sq. ft. and this has been used in the estimates. Add for stairways, elevator wells, plumbing, partitions and special work.

Deductions from Diagrams.—(1) An examination of the diagrams shows immediately the decrease in cost as the width is increased.

This is due to the fact that the cost of the walls and outside foundations, which is an important item of cost, relative to the total cost, is decreased as the width increases.

For example, supposing a three-story building is desired with 30,000 sq. ft. on each floor:

If the building were 600 ft. x 50 ft., its cost would be about 99 cts. per sq. ft.

If the building were 400 ft. x 75 ft., its cost would be about 87 cts. per sq. ft.

If the building were 300 ft. x 100 ft., its cost would be about 83 cts. per sq. ft.

If the building were 240 ft. x 125 ft., its cost would be about 80 cts. per sq. ft.

(2) The diagram shows that the minimum cost per square foot is reached with a four-story building. A three-story building costs a trifle more than a four-story. A one-story building is the most expensive. This is due to a combination of several features:

(a) The cost of ordinary foundations does not increase in proportion to the number of stories, and therefore their cost is less per square foot as the number of stories is increased, at least up to the limit of the diagram.

(b) The roof is the same for a one-story building as for one of any other number of stories, and therefore its cost relative to the total cost grows less as the number of stories increases.

(c) The cost of columns, including the supporting piers and castings, does not vary much per story as the stories are added.

(d) As the number of stories increases, the cost of the walls, owing to increased thickness, increases in a greater ratio than the number of stories, and this item is the one which in the four-story building offsets the saving in foundations and roof.

(3) The saving by the use of frame construction for walls instead of brick is not as great as many persons think. The only saving is in somewhat lighter foundations and in the outside surfaces of the building. The floor, columns, and roof must be the same strength and construction in any case.

Assumed Height of Stories.—From ground to first floor, 3 ft. Buildings 25 ft. wide, stories 13 ft. high. Buildings 50 ft. wide, stories 14 ft. high. Buildings 75 ft. wide, stories 15 ft. high. Buildings 100 ft. wide, stories 16 ft. high. Buildings 125 ft. wide, stories 16 ft. high.

Unit Prices.—Floors, 32 cts. per sq. ft. of gross floor space not including columns. If columns are included, 38 cts.

Roof, 25 cts. per sq. ft., not including columns. If columns are included, 30 cts. Roof to project 18 ins. all around buildings.

Stairways, including partitions, $100 each flight. Allow two stairways, and one elevator tower for buildings up to 150 ft. long. Allow two stairways and two elevator towers for buildings up to 300 ft. long. In buildings over two stories, allow three stairways and three elevator towers for buildings over 300 ft. long.

In buildings over two stories, plumbing $75 for each fixture including piping and partitions. Allow two fixtures on each floor up

TABLE IVA.—RATIO OF COST OF VARIOUS BUILDINGS TO THAT OF BRICK MILLS, STANDARD CONSTRUCTION.

Superficial feet of floor in 1 sty.	Frame Mills. 1 Sto.	2 Sto.	3 Sto.	4 Sto.	5 Sto.	6 Sto.	Brick Store House. 1 Sto.	2 Sto.	3 Sto.	4 Sto.	5 Sto.	6 Sto.	Frame Store House. 1 Sto.	2 Sto.	3 Sto.	4 Sto.	5 Sto.	6 Sto.
1,250	.86	.67					.80	.73					.70	.51				
2,500	.86	.73					.85	.73					.75	.58				
5,000	.89	.78	.75	.73	.70	.67	.83	.80	.78	.76	.76	.75	.74	.60	.56	.53	.51	.48
7,500	.90	.79	.77	.74	.71	.69	.85	.81	.78	.77	.76	.76	.77	.63	.58	.55	.53	.51
10,000	.90	.80	.78	.75	.73	.70	.87	.81	.79	.78	.77	.76	.78	.65	.60	.57	.55	.53
15,000	.91	.82	.79	.77	.75	.72	.89	.83	.81	.79	.78	.78	.81	.67	.64	.61	.59	.56
20,000	.92	.83	.81	.79	.77	.74	.90	.84	.82	.80	.80	.79	.82	.70	.67	.64	.61	.59
25,000	.92	.85	.82	.80	.78	.76	.91	.85	.83	.82	.81	.80	.83	.72	.69	.66	.63	.61
30,000	.93	.86	.84	.81	.80	.77	.91	.86	.84	.82	.81	.81	.84	.73	.70	.67	.65	.62
35,000	.93	.87	.84	.82	.80	.78	.92	.86	.84	.83	.82	.81	.85	.74	.71	.68	.66	.63
40,000	.93	.87	.85	.83	.81	.79	.92	.87	.85	.84	.83	.82	.86	.75	.72	.69	.67	.64
45,000	.94	.87	.85	.83	.82	.79	.92	.87	.85	.84	.83	.82	.86	.76	.72	.70	.67	.65
50,000	.94	.88	.86	.84	.82	.80	.92	.88	.86	.84	.83	.83	.87	.77	.73	.71	.69	.66

to 5,000 sq. ft. of floor space and add one fixture for each additional 5,000 sq. ft. of floor or fraction thereof.

(Note.—From the above data the approximate cost of any size and shape of building can be estimated in a few minutes. After the cost of the items given is determined about 10% should be added for incidentals.)

Reinforced Concrete Buildings.—From such estimates and proposals as I have been able to get and from work done it appears that the cost of reinforced concrete buildings designed to carry floor loads of 100 lbs. per sq. ft. or less would be about 25% more than the slow-burning type of mill construction.

Alternate Method of Estimating Cost.—Floors.—38 cts. per sq. ft. of gross floor space. This price will include column piers, column castings and wrought iron.

Roof.—30 cts. per sq. ft., including projections, say 18 ins., including columns, etc.

Stairways and Elevator Towers.—Allow two stairways and one elevator tower in buildings over two stories high up to 150 ft. long. Allow two stairways and two elevator towers up to 300 ft. long. Allow three stairways and three elevator towers over 300 ft. long.

Brick Walls.—Enclosing stairs and elevators, estimated as inside walls.

Stairs.—$100 per flight, per story.

Plumbing.—Allow two fixtures on each floor up to 5,000 sq. ft. of floor space, and add one fixture for each additional 5,000 sq. ft. or fraction thereof. Allow $75 per fixture.

Incidentals.—Add about 10% for incidentals.

TABLE V.—DATA FOR ESTIMATING COST OF BUILDINGS.

	Foundations including exc. Cost per lin. ft. for outside walls.	inside walls.	Brick Walls. Cost per sq ft. of surface. outside walls.	for inside walls.	Columns including piers and castings. Cost of one.
One story building	$2.00	$1.75	$ .40	$ .40	$15.00
Two story building	2.90	2.25	.44	.40	15.00
Three story building	3.80	2.80	.47	.40	15.00
Four story building	4.70	3.40	.50	.43	15.00
Five story building	5.60	3.90	.53	.45	15.00
Six story building	6.50	4.50	.57	.47	15.00

TABLE VI.—DATA FOR APPROXIMATING COST OF MILL BUILDINGS OF KNOWN SIZE BUT WITHOUT DEFINITE PLANS MADE.

Height of Building.	Foundations. including exc. Cost per lin. ft. for outside walls.	inside walls.	Brick walls. Including doors and windows Cost per lin. ft. of surface. outside walls.	for inside walls.
One story	$2.00	$1.75	$ .40	$ .40
Two stories	2.90	2.25	.44	.40
Three stories	3.80	2.80	.47	.40
Four stories	4.70	3.40	.50	.43
Five stories	5.60	3.90	.53	.45
Six stories	6.50	4.50	.57	.47

Estimating Quantity of Lumber.—Lumber is measured in feet board measure, as explained on page 487.

There are 15 or more associations in America having rules governing the inspection and classification of lumber. The following three have printed rules that are particularly valuable to have: The National Hardwood Lumber Association, Chicago; Southern Lumber Manufacturers' Association, St. Louis; Mississippi Valley Lumbermen's Association, Minneapolis, Minn.

In building a house, there is always a considerable percentage of waste lumber. Then, too, there is the loss in surface area in forming tongues and grooves at the mill, and in dressing the edges. Therefore, after computing the exact number of pieces, or the exact area, as shown in the plans for the building, it is necessary to add considerably to the lumber bill to cover the waste.

To estimate the number of *joists* for each room, count the actual number and add 1 joist; for an extra joist is needed for the wall. Joists are nearly always "bridged," and for this purpose 2 x 4-in. stuff is used. The "bridging" is the inclined bracing between the joists.

Allow 25 lin. ft. of 2 x 4-in. bridging for each "square" (100 sq. ft.) of flooring. Where 2 x 12-in. joists are placed 16 ins. apart, it will be found that the 2 x 4-in. bridging amounts to about 9% of the number of ft. B. M. of joists.

On a plain roof count the number of *rafters* and add 1 extra.

In estimating the number of *studs* for walls and partitions, allow 1 stud for every lineal foot of wall or partition where studs are "spaced 16 ins. centers," that is 16 ins. center to center. This seemingly large allowance is made to cover the doubling of studs on corners, doors and windows. For a stable or shed no such extra allowance need be made.

To estimate the quantity of *sheeting* or of *shiplap*, calculate the exact surface to be covered, deducting openings, then add the following percentages:

	Sheeting. Per cent.	Shiplap. Per cent.
For floors	15	17
For sidewalks	17	20
For roofs	20	25

Sheeting is laid with 2-in. spaces on cheap roofs, then deduct accordingly. Sheeting and shiplap are sometimes laid diagonally, then add 5% to the above figures to cover waste in sawing both ends.

Remember that lumber comes in lengths of even feet, and, with few exceptions, 16 ft. is the maximum stock length. Examine each area to be covered to see whether a given number of standard lengths will cover it, or whether there will be a waste on each length.

To estimate the amount of *siding*, calculate the exact surface, deducting openings, and add 33%, if 6-in. siding with 4½ ins. to the weather; but if it is 4-in. siding add 50% to the actual surface.

There are two classes of *flooring*, namely, "dressed or square edge flooring," and "dressed and matched flooring." The square

edge flooring ordinarily has a face width about ½ in. less than its nominal width; thus, a piece of 6-in. square edge flooring has a face width of 5½ ins., and a piece of 4-in. flooring has a face width of 3½ ins. The loss in the case of the flooring with 5½-in. face is 9%, and in the case of the 3½-in. face, the loss is 14%. But in addition to these mill losses, there is generally waste owing to bad ends, etc., so that after estimating the exact area of floor, add the following percentages:

	Per cent.
For 6-in. flooring, add	11
For 4-in. flooring, add	20

The following gives a fair extra allowance where dressed and matched flooring is to be laid:

	Per cent.
For 6-in. flooring, add	17
For 4-in. flooring, add	25
For 2¼-in. flooring, add	33
For 1¾-in. flooring, add	40

Remember that if the flooring is to be laid under partitions, due allowance must be made. If the architect has so spaced the joists that full standard lengths can not be used, there may be a very large waste not included in the above allowances; thus, if the width of room is such as to require flooring 12 ft. 2 ins. long, it will be necessary to buy flooring 14 ft. long, and saw off nearly 2 ft., which is wasted. Flooring less than 1 in. thick is estimated as being 1 in. thick.

Ceiling and *Wainscoting* are estimated just as dressed and matched flooring is estimated.

Cost of Timberwork in 5 Different Kinds of Buildings.—In the following table is given the average cost of timberwork in a number of different buildings. Each building is briefly described in the table, and the cost is the average of all the rough lumber in it, and does not include the work on the milled, or dressed lumber. Only carpenters were engaged on this work, and they handled all the lumber after its delivery in wagons at the site of the work. Wages of carpenters were 40 cts. per hr. No common laborers employed.

Building number		Ft. B. M. per man per day of 8 hrs.	Cost per M., wage being $3.20 for 8 hrs.
1	A block of six 3-story "flats," first story veneered with brick; rest covered with slate; an expensive front; towers.....	275	$11.60
2	Same type of building with a plain front	375	8.50
3	Three-story schoolhouse, plain; including sheeting, shiplap, and all plain lumber except flooring.....................	400	8.00
4	Three-story business building...........	475	6.80
5	Heavy warehouse, mill construction.....	550	5.80
6	A plain two-story building, with a 2-in. flooring roof, and plank under-floors...	385	8.30

Cost of Framing and Placing Lumber.—The following table gives the actual cost of the carpenter work involved in doing the different classes of work enumerated. No common laborers were employed.

	Ft. B. M. per man per day of 8 hrs.	Cost per M., wage being $3.20 for 8 hrs.
Joists: In a four-story brick business block, having steel girders, 3 x 14-in joists delivered sized, average cost of work on joists and sheeting (not including hoisting which was $2 per M. for second story and up)	550	$ 5.80
Joists: In a three-story, plain, electric light building, with flat roof, 3 x 12-in. joists, including sizing of joists	400	8.00
Joists and floor: In a warehouse, joists dropped into stirrups, and a heavy plank floor	500	6.40
Bridging: 2 x 4-in. bridging between joists	150	21.30
Sleepers: For a railroad machine shop, 6 x 8-in. sleepers buried in sand	380	8.40
Plank floor: The 3-in. plank floor laid on the sleepers above described	450	7.10
Purlins: For a warehouse, including hoisting 60 ft.	265	12.10
Plank floor: A 2-in. plank floor laid on purlins that were 6-ft. apart	230	13.90
Sheeting for floors	800	4.00
Sheeting for roof of six-story building	500	6.40
Sheeting on frame building	500	6.40
(Note.—If sheeting is laid diagonally, add 15% to the cost of laying.)		
Rafters: 2 x 6-in. rafters for plain gable roof	300	10.70
Rafters: 2 x 6-in. rafters for a hip roof	125	25.60
Roof boards: Rough boards on a plain gable roof	600	5.35
Roof boards: Rough boards on a hip roof	400	8.00
Siding: Rough boards on a barn	800	4.00
Studding: 2 x 4-in.	250	12.80
Studding: 2 x 6-in.	350	9.15
Sills and plates: 6 x 8-in., without gains or mortices	400	8.00
Sills and plates: 6 x 8-in., with gains but no mortices	200	16.00
Sills and plates: 6 x 8-in., with gains and mortices	135	23.70
Platform: A rough timber platform on short posts, around a warehouse, including posts, caps, joists and floor	400	8.00
Board fence: A close board fence, 8-ft. high (posts already set)	400	8.00

Cost of Laying and Smoothing Floors.—In the following table is given the cost of laying matched flooring, after the joists are in place. All the cost of handling the flooring after its delivery at the building site is included. Where the width of the flooring plank is given, the face width is meant, and it should be remembered that the face width is about ½-in. less than the original stock width of the material before milling. A flooring that is sold by the mills as 4-in. plank, has a face width of 3½ ins. The cost of laying is given in "squares" of 100 sq. ft.

COST OF LAYING FLOORING.

	Squares per man per day of 8 hrs.	Cost per square, wages being $3.20 per 8 hrs.
Yellow pine: 3¼-in. face laid on sheeting, including the laying of paper between the sheeting and the flooring and including the smoothing of rough joints in the flooring, in a four-story business block	2	$ 1.60
Yellow pine: 3¼-in. face, including smoothing and sandpapering, in a five-story business block, men worked very hard	1¾	1.80
Yellow pine: 3¼-in. face, laid direct on joists, no smoothing	3	1.10
Maple: Square edged, 4-in. face, doubled nailed, not smoothed, in a warehouse	2¼	1.40
Yellow pine: 4-in. face, nailed on one edge only, not smoothed, in a six-story warehouse	2½	1.30
Yellow pine: 3¼-in. face, including smoothing and sandpapering, in a three-story seminary, ground floor	1½	2.10
Ditto: Small upper rooms	1¼	2.60
Maple: 2¼-in. face, laid but not smoothed	2	1.60
Maple: 2¼-in. face, laid but not smoothed, large floor of warehouse	3½	0.90
Maple: 2¼-in. face, laid and smoothed, houses and offices	1	3.20
Maple: 1¾-in. face, laid and well smoothed, houses and offices	¾	4.30
Maple: Smoothing only, not including laying the floor	1	3.20
Oak: Gluing, smoothing, scraping and sandpapering a fine floor, men working hard	¼	12.80
Yellow pine: 5¼-in. face, 2 ins. thick, tongue and groove, for mill building, not smoothed	2½	1.30
Yellow pine: 5¼-in. face on bare joists, not smoothed	4	0.80
Ditto: Laid on top of an under-floor	3	1.10
Ditto: Laid on a pitched roof without many angles	2	1.60

Cost of Ceiling, Wainscoting and Siding.—The following table gives the cost of ceiling, wainscoting and siding:

	Squares per man per day of 8 hrs.	Cost per square, wages being $3.20 per day.
Ceiling of a store	1½	2.10
Smoothing an oak ceiling after laying	¾	4.30
Wainscoting: Cut, put up and finished with cap and quarter round	1¾	1.80
Siding: Plain, 6-in.	2¼	1.40
Drop-siding: When window casings and corner boards are placed over the siding	4	0.80
Drop-siding: When joints are made against casings and corner beads	2½	1.30
Lap-siding	3	1.05
Surfaced barn boards	7	0.45

Cost of Shingling.—The following table gives the cost of laying shingles, shingles being well laid with 4½-in. exposure:

	Squares per man per day of 8 hrs.	Cost per square, wages being $3.20 per day.
Plain roof	2½	$1.30
Fancy roof	1¾	1.80
Difficult roof, much cutting	1	3.20
Plain side walls	1½	2.10
Difficult side walls	1	3.20

The standard bunch of shingles is supposed to contain 250 shingles averaging 4 ins. wide. Hence if shingles are laid with an exposure of 4½ ins., each shingle covers 4 × 4½ = 18 sq. ins., or 800 shingles to the square. But the cutting for angles, the loss of broken shingles, the double course at the eaves, and the like, necessitate a larger allowance. On plain roofs allow 8% more, and on gables 12% more than the theoretical 800. Estimate as follows:

	Plain roof. Shingles per square.	Cut-up roof. Shingles per square.
With 4-in exposure	990	1010
With 4½-in. exposure	880	900
With 5-in. exposure	790	810

Cost of Laying Base-Boards.—The amount of base-board work is computed in lineal feet, instead of board feet. The following costs relate to the actual number of lineal feet, doors and openings being deducted:

	Lin. ft. per man per day of 8 hrs.	Cost per lin. ft. wages being $3.20 per day.
Base-board: In a building with an unusually large number of pilasters	50	6½ cts.
Base-board: Three-membered, hardwood, average number of miters	50	6½ cts.
Base-board: In a plain five-story business block, two-membered base scribed to floor	80	4 cts.
Base-board: In a three-story seminary, narrow birch; fitting to the floor not necessary	100	3¼ cts.
Base-board: Plain, quarter-round at floor	100	3¼ cts.
Moulding: Bed, flat, 3-in	320	1 ct.

Cost of Placing Doors, Windows and Blinds.—The following table gives the cost of labor on doors, windows and blinds:

	Number of hrs. labor on each.	Labor cost of each, wages being 40 cts. per hour.
Windows: To put frames together if stuff comes knocked down	1½	$ 0.60
Window: Ordinary pine window in a frame building including setting frame	5	2.00
Window: Same as before, except hardwood	6½	2.60
Window: Ordinary pine window in brick building, including setting frame	6½	2.60
Window: Same as before, except hardwood	9	3.60
Window: 30-light (lights 10 x 14), setting frame, fitting and hanging sash, and putting on hardware, for a machine shop	7	2.80
Window: Same as before, but hung on sash balances	6	2.40
Transom: Fixed	1	0.40
Transom: Hung	1½	0.60
Door: Common hardwood, set jambs, case, hang and finish, including transom	10	4.00
Door: Birch door, complete, for a seminary	7	2.80
Door: Common pine door, 1⅜-in., complete	4½	1.80
Door: Common pine, 1¾-in., complete	5½	2.20
Door: Pine, swinging door, no hardware except hinges	4	1.60
Door: Pine, finish of wide paneled jambs, with transom, for school house	10	4.00
Door: Same as before, but hardwood	12½	5.00
Sliding doors: Pine (framing not included), to finish complete with lining, jambs, casings, and hardware, per pair	32	12.80
Sliding doors: Same as before, but hardwood, per pair	48	19.20
Outside doors: Pine, 6 x 8 ft., door frame, casings, and hardware, complete, per pair	10	4.00
Outside doors: Same as before, but hardwood, per pair	14	5.60
Outside double doors: Opening 12 x 18 ft., in a factory	32	12.80
Sliding doors: Opening 12 x 18 ft., in a barn	24	9.60
Blinds: If fitted before frames are set, per pair	¾	0.30
Blinds: If fitted after frames are set, per pair	1	0.40
Blinds: Plain pine, inside blinds, per set	3	1.20
Blinds: Same as before, but hardwood	5	2.00

The labor cost of bedding and setting 10 x 14-in. lights on a large building was 1½ cts. per light, or 1½ cts. per sq. ft.; and one-twenty-fifth of a pound of putty per lineal foot around the edge of the glass was used. With a deeper rabbet and putty not properly pressed, one-fifteenth pound per lineal foot of glass edge may be used. The cost of setting plate glass is about 7 cts. per sq. ft. Floor and sidewalk glass may be set for 5 cts. per sq. ft.; skylight glass for 8 cts. per sq. ft.

Cost of Closets and Sideboards.—The following miscellaneous labor costs will serve as a guide: The labor costs are given in dollars and cents, wages being 40 cts. per hour:

	Cost of Labor.
Drawers, if dovetailed, each	$ 1.00
Drawers, 15 ins. wide, 18 ins. deep, including racks and fittings, each	0.80
Shelves, in a storeroom, shelves dadoed into compartments 18 ins. square, per sq. ft. of shelf	0.25
Shelves, in pantry, no dadoing, per sq. ft.	0.15
Closet hooks, on a strip of wood, hooks 12 ins. apart, per lin. ft. of strip	0.06
Sideboard, ash, 8 x 8 ft., drawers, doors, brackets, shelves, mirrors and hardware	50.00
Sideboard, oak, less detail than before	40.00
Sideboard, pine, fairly good	25.00

Cost of Making Stairs.—The labor cost of making a number of different kinds of stairs will be given, labor being 40 cts. per hour. The cost includes the making and setting of the stairs, but does not include mill work.

	Cost of Labor.
Two flights of stairs (for a school), 6 ft. wide, with ceiling rail	$ 35.00
Three flights of oak stairs (for a hospital), 5 ft. wide with continuous rail	90.00
Three flights of oak stairs (for a seminary)	120.00
Box-stair, long, without landing	9.00
Box-stair, for cellar or attic, if windows are used	10.00
One flight of plain stairs, in a 7-room house	16.00
One flight of fine stairs, in a 9-room house	40.00

Cost of Tin Roofing.—The sizes of tin sheets are 14 x 20 ins., and 20 x 28 ins. An allowance of 1 in. must be made for laps at joints; with sheets 20 x 28 ins., a square (100 sq. ft.) requires 29 sheets. With 14 x 20-in. sheets, allow 63 per square, and 50% more of solder, rosin, etc. A box of tin contains 112 sheets, and the large sheets of I. C. tin weigh 225 lbs. per box; the I. X., 285 lbs. per box.

One man, at 40 cts. per hr., will lay 2 squares of plain roofing per day. One man will line about 75 sq. ft. of box gutter, or an equal amount of flashing, per day. The cost per square of tin roof was as follows:

	Per square.
29 sheets of I. C. tin, 55 lbs., at 8 cts.	4.40
5 lbs. solder, at 14 cts.	0.70
1½ lbs. nails, at 4 cts.	0.06
1 lb. rosin	0.04
Labor, at 40 cts. per hr.	1.60
Charcoal	0.10
Painting two coats	1.50
Total	$8.40

A man, at 40 cts. per hr., will put up plain metal ceilings at the rate of 1½ to 2 squares per day, including cornice and centers. On a large room, and plainest kind of work, he may do 3 or 4 squares. Wainscoting, at the same rate.

A man, with a helper, will lay 12 squares of corrugated iron roofing in a day.

Building Papers and Felts.—The cheapest grade of building paper is "rosin-sized" paper. It is not waterproof, and should not be used on roofs, or on walls in a damp climate. It comes in rolls 36 ins. wide, containing 500 sq. ft., weighing 18 to 40 lbs., and costs about 3 cts. per lb.

There are a number of different kinds of waterproof papers used for sheathing under siding or shingles. P. & B. building paper, for example, is coated with a paraffin compound. It comes in rolls 26 ins. wide containing 1,000 sq. ft. The weights per roll are:

Ply	1-ply.	2-ply.	3-ply.	4-ply.
Weight	30 lbs.	40 lbs.	65 lbs.	80 lbs.

Price is 10 cts. per lb.

Common dry felts are made of wood fibers cemented together with rosin. They weigh about 5 lbs. per 100 sq. ft. The best grades of dry felt are made of wool, and weigh 11 lbs. per 100 sq. ft. when they are ⅛-in. thick; but some brands are 50% heavier than this. The price of dry wool felt is about 2¼ cts. per lb.

Tar felt, or common roofing felt, is made by saturating common dry felt with coal tar. The weight of a single layer or ply is 12, 15 or 20 lbs. per 100 sq. ft., but the felt is laid in several layers, usually 4 or 5-ply, in making a roof, each layer being mopped with a "composition" of ⅓ tar and ⅔ pitch. The price of tar felt is about 1½ cts. per lb.

There are many kinds of patent roofing felts. Ordinarily they come in rolls 29 ins. wide, and each roll covers a square, allowing 2 ins. for the lap. Nails and cement are supplied with each roll by the manufacturers. The cost of the roofing is $3 to $5 per square, and the cost of laying it is about 1 hr. labor per square, or 40 cts. The weight of such roofing varies considerably, but ordinarily is about 100 lbs. per 100 sq. ft.

Cost of Gravel Roofs.—Tar felt, 4 or 5-ply, is first laid, the sheets being mopped with "composition" of ⅓ tar and ⅔ pitch. Screened roofing gravel is spread over the roof. A square of gravel roof costs about as follows:

	Per square.
1-6 cu. yd. (450 lbs.) gravel, at $2.40	$0.40
40 lbs. tar, at 1½ cts.	0.60
80 lbs. pitch, at 1½ cts.	1.20
100 sq. ft. felt, 4-ply, 75 lbs., at 1½ cts.	1.13
Labor, at 35 cts. per hr.	0.70
Total per 100 sq. ft.	$4.03

Note.—About 20 lbs. of "composition" per square per ply is ordinarily sufficient where sheets are mopped only at the joints instead of all over; but in the above the sheets are assumed to be mopped all over, which takes 50% more composition.

Tar is usually sold by the gallon, or by the oil barrel holding 50 gallons, present prices being 12 cts. per gallon. Tar weighs almost exactly as much as water, or 8⅓ lbs. per gallon.

Cost of Slate Roofs.—Roofing slate comes in a great variety of sizes, the most common of which are 16 x 8, 16 x 10, and 18 x 9 ins.; but sizes as large as 25 x 14, and as small as 12 x 6, are made. To determine the number of pieces to a square, deduct 3 ins. from the length (for the lap), divide this by 2, multiply by the width of the slate, and divide the result into 14,000. An 18 x 9 slate would be estimated thus: $18 - 3 = 15$, which divided by 2 gives $7\frac{1}{2}$; then $7\frac{1}{2} \times 9 = 67\frac{1}{2}$; then $14{,}400 \div 67\frac{1}{2} = 214$ pieces.

Slates are sold by the square, that is a sufficient number of slates to lay 100 sq. ft., each course having a lap of 3 ins. over the head of those in the *second* course below. The price f. o. b. Pennsylvania and Vermont quarries varies according to the grade; but a good No. 1 slate, 3/16-in. thick, can be bought for $5 per square. The freight from Pennsylvania or Vermont to the Mississippi River is about $2.50 per square. Allow about 1% waste, unless the roof is perfectly plain.

The weight of 1 sq. ft. of slate ¼-in. thick is 3.6 lbs. As there are 214 pieces of 18 x 9-in. slate per square of roof; and if it were all ¼-in. thick, the weight would be 868 lbs.; if it were 3/16-in. thick, the weight would be 621 lbs.

Before laying the slate, the roof is covered with paper. A 50-lb. roll will cover 400 sq. ft., and with wages at 40 cts. per hr., the cost of laying the paper is 20 cts. per square. The holes for the nails must be punched in the slate before laying. This may be done by the manufacturers, but it is usually done by hand by the slaters, because if a corner is broken off in transport the slate can be turned end for end, moreover as slate usually comes in three thicknesses it must be sorted anyway before laying, and the punching can as well be done at the same time. One slater, at 40 cts. per hr., with a helper, at 20 cts. per hr., will punch the holes in 10 x 16-in. slates at a cost of 45 cts. per square.

In laying slates, about one laborer is required for two slaters on plain roofs. A slater will punch and lay 3 squares per 8 hrs. on plain straight work, 2 squares on roofs with many hips and valleys, and as low as 1 square on difficult tower work. For fair average work allow 2½ squares per day per slater, and allow 1 laborer to 2 slaters. This includes punching, and laying paper and slate. The cost of a slate roof, 10 x 16-in. slates, was as follows:

	Per square.
Slate for 1 square	$ 5.00
Freight (650 lbs.)	2.50
Loading and hauling	0.20
Wastage, 1% of $7.70	0.08
16 lbs. paper	0.50
1 lb. nails	0.05
2½ lbs. of 3d galv. nails for slate	0.10
Slater, at 40 cts. per hr.	1.30
Helper, at 20 cts. per hr.	0.30
Total per square	$10.03

Cost of Roofs.—In the Proceedings Assoc. Ry. Supts. of Bridges and Buildings, 1902, a committee report gives the following costs of roofs in New England.

	Per square.
Slate	$ 9.00 to $12.00
Tile	30.00 to 33.00
Cedar shingles	4.50 to 5.00
Tinned shingles	5.00 to 6.50
Sheet tin	6.50 to 8.00
Tar and gravel	4.00 to 5.00
Ruberoid	2.75 to 3.75
Paroid	3.00 to 3.50
Tar paper, two-ply, laid double	2.00 to 2.25
Tar paper, three-ply, laid single	1.50 to 2.00

Instances were cited of slate roofs 40 years old. Shingle roofs 28 years old were cited, but 15 years seemed to be the ordinary life of good shingles. Tar and gravel roofs 30 years old were cited, but an ordinary life seemed to be 12 to 18 years.

Cost of Ferroinclave Roof.—This type of roof was invented by Mr. Alexander Brown, vice-president of the Brown Hoisting Mchy. Co. It consists of corrugated sheet steel plastered on both sides with Portland cement mortar, giving a total thickness of 1¼ ins. The corrugations are in the form of a dovetail. The steel sheets are laid on purlins spaced 4 ft. 10 ins., and clipped to them. The cement mortar is mixed 1:2, and that used on the under side contains a small amount of lime and hair. When the cement has set for 10 days, the upper side is painted with two coats special paint.

The cost per square (100 sq. ft.) is said to be as follows:

	Per sq.
Ferroinclave sheets	$ 8.50
Fastening clips	0.48
Laying Ferroinclave	1.25
Cement mortar on upper side	3.00
Cement mortar on lower side	4.00
Waterproofing paint	1.50
Sundries, freight, supt., etc.	1.27
Total	$21.00

The weight is about 15 lbs. per sq. ft.

Brick Masonry Data.—The size of common bricks varies widely. I have seen bricks as small as 2 x 3¼ x 7½ ins. used for house building in New York City. In the New England States, common bricks are said to average about 2¼ x 3¾ x 7¾ ins. In most of the Western States, common bricks average 2½ x 4⅛ x 8½ ins. The size of individual bricks in a car load often varies considerably; hard bricks being ⅛ to 3/16-in. smaller than soft (or salmon) bricks. Pressed or face bricks are quite uniformly 2⅝ x 4⅛ x 8⅜ ins. A thousand bricks, averaging 2¼ x 4 x 8¼ ins. weigh 5,400 lbs., if there is any standard size it may be said to be 2¼ x 4 x 8¼ lbs., and they weigh 125 lbs. per cu. ft.; and they occupy 43.2 cu. ft. of space, which is equivalent to 23¼ bricks per cu. ft., if no allowance is made for joints. If these bricks are laid in massive masonry with ½-in. joints, about 430 bricks will be required per

cu. yd., or 16 per cu. ft.; if laid with ¼-in. joints, 515 bricks per cu. yd., or 19 per cu. ft.

Masons have empirical rules for estimating the number of bricks in a wall. Their rules do not give even an approximation to the actual number, or "kiln count." They often make no deductions for openings, but use a "wall measure" rule, allowing 7½ bricks per sq. ft. (or per superficial foot) for a wall that is a "half brick thick," that is a 4-in. wall. For "one-brick" wall, that is 8 or 9 ins. thick, they estimate 15 bricks per sq. ft. For a "one-and-a-half-brick" wall (12 or 13 ins. thick), they estimate 22½ bricks per sq. ft. This rule takes no account of the actual size of the bricks, and does not, therefore, give "kiln count," but gives "wall count." We have seen, above, that "standard size" bricks, laid with ½-in. mortar joints, will actually average 16 per cu. ft., as compared with 22½ per cu. ft. "wall count."

If all the broken bricks, or "bats," were thrown away, the wastage would be about 2% with fair bricks to 5% with poor bricks; but it not often that contractors are prohibited by inspectors from using practically all the "bats."

The cost of loading and hauling paving bricks is given on page 158, and practically the same costs apply to building bricks, except that the latter are lighter. As above stated, the "standard size" hard brick weighs about 5.4 lbs., or 2.7 tons per M., or 125 lbs. per cu. ft. Soft bricks weigh 20% less, but repressed bricks weigh 20% more per cubic foot. With wages at 15 cts. per hr., the cost of unloading cars into wagons is 30 cts. per M., and, unless a dump wagon is used, it costs another 30 cts. per M. to unload the wagons.

Cost of Laying Brick.—In building brick walls there are usually 1 to 1½ laborers to each brick mason. The laborers mix mortar and carry mortar and bricks to the masons, using hods for the purpose. A hod holds about 18 bricks, or approximately 100 lbs. The wages of masons and hod carriers vary widely in different cities, but seldom exceed $5 per 8-hr. day for masons and $3 for hod carriers. Very often the masons' unions have forced up their rates of wages, but the hod carriers have not, and may receive but little more than other common laborers. With wages as just given, and one helper to each mason, the labor cost of laying should not exceed $6 per M. for common brick, and $10 per M. for pressed (face) brick, "kiln count" in both cases.

On a three-story brick hospital, with a carefully laid front (½-in. "shoved" joints), the labor cost was $5.50 per M., "kiln count." There were three laborers to every two masons, and wages were 17½ cts. per hr. for laborers, and 45 cts. per hr. for masons, working 9 hrs. The cost of the masons' wages amount to $3.50 per M., and the cost of the helpers' wages was $2 per M. This cost was rather high, due to the number of deep flat brick arches over basement openings, and to the row-lock arches over other openings, as well as a tower and other puttering work.

In building warehouses, where the work was plain, wages being as just given, the cost was $4 per M., "kiln count."

On several large city buildings, in which 15 to 20% of the brick masonry was pressed brick, each brick mason laid the following average number, "kiln count," per 9-hr. day:

Apartment house, 4 stories	1,200
Four-story fronts	1,250
Heavy walls, ground level	1,500
Heavy footings and warehouse basement walls.	3,200

A bricklayer should lay 400 or 500 pressed brick per 8-hr. day. If an ornamental brick front is to be laid, with molded arches, buttresses with bases and caps, etc., the labor of laying pressed brick may run as high as $20 per M.

In veneering a frame building with brick, a mason will average 400 bricks per day.

In building brick arches to support the sidewalk in front of a city building, after the centers were set, each bricklayer averaged 1,800 bricks per 9-hr. day; and it required one man to make and deliver mortar and to deliver brick to every two bricklayers. The brick arches were 5-ft. span, 11 ft. long, and 4 ins. thick.

Cost of Mortar.—With lime mortar, mixed 1 part lime to 3 parts sand, it required 0.9 bbl. lime per M. of bricks, "kiln count," the bricks being laid with ⅜-in. joints. A common allowance in estimating the cost of mortar, for "standard size" bricks, is 1 bbl. lime and 0.6 cu. yd. sand per M., "kiln count." About ⅓ cu. yd. of mortar is usually allowed per cu. yd. of brick masonry, or 0.7 cu. yd. mortar per M. of bricks, when bricks are laid with ½-in. joints. If cement mortar is used, the number of barrels of cement per cubic yard of mortar will be found on page 253. It will seldom require less than 1.6 bbls. of cement per M. of bricks, or 0.8 bbl. per cu. yd. of brick masonry, for if the mortar is made leaner it will not trowel well, and cause more loss in labor than is saved in cement.

Rockland, Me., lime is sold by the barrel, 220 lbs. net. When shipped in bulk 2½ bu., of 80 lbs. per bu., are usually called a barrel. A barrel holds about 3.6 cu. ft. The average yield of lime paste from the best limes is 2.6 bbls. of paste for each barrel of quick lime. This paste is usually mixed with 2 parts sand by measure. It, therefore, takes about 1⅓ bbls. of the best quick lime to make 1 cu. yd. of mortar. A poor lime does not make ¾ as much paste as a good lime.

The price of lime is about 60 cts. per bbl.

Cost of Brickwork in a Railway Repair Shop.*—Below is given the labor cost of some brickwork done in October, 1896, for the Detroit, Lansing & Northern R. R. The work consisted of building the walls of the railroad repair shop at Ionia, Mich. The work was done by contract, the contractors, however, furnishing only the labor, this being done for a lump sum; the materials were furnished by the railroad company. The face bricks were new, but the back was of bricks which came from an old building. The size of the bricks was 2⅝ x 3¾ x 8 in., and the joints were from ⅜-in. to ½-in. in thickness. According to these figures about 20 bricks were

*_Engineering-Contracting_, May 16, 1906.

used to the cubic yard, and that number was used in computing the number of bricks in the building. In the summary is given the actual cubic contents of the walls, all openings being deducted.

As the walls were only 20 ft. high, scaffolds and runways were built so that wheelbarrows could be used throughout the entire work for tending masons. The cost of laborers was thus reduced. The scaffolding was built by the railroad company. The wages allowed were as follows: Foreman, 40 cts. per hr.; mason, 30 cts. per hr.; laborers, 12½ cts. per hr. The weather was favorable for good work.

Cubic ft. built	5,204.3
Bricks laid	104,086
Foreman, hrs.	161
Mason, hrs.	439
Laborers, hrs.	509

The average number of bricks laid per mason per hour was 173, including the time of the foreman, who was a mason and worked also.

The labor costs were as follows:

Mason's wages	$196.10
Laborer's wages	66.63
Mason's wages per cu. yd.	1.02
Mason's wages per M brick	1.88
Laborer's wages per cu. yd.	0.33
Laborer's wages per M brick	0.61
Total cost of masons and labor per cu. yd.	1.35
Total cost of masons and labor per M	2.49

From the above figures the cost of labor for similar work can be estimated as follows: Labor cost of 1 cu. yd. brickwork is equal to 5/6-hour wages of foreman, plus 2¼ hours wages of mason, plus 2⅝ hours wages of laborer. In the same manner, the cost of laying 1,000 brick is equal to 5/6-hour wages of foreman, plus 4¼ hours wages mason, plus 4⅞ hours wages laborer.

In the work it was found that 0.44 cu. yd. of sand and 10-11 bbl. (bulk) lime were required to lay 1,000 brick with ⅜-in. to ½-in. joint. One barrel of lime equaled 3⅝ cu. ft. and weighed 201 lbs., the weight being figured from car weight. Accordingly 1 bbl. (bulk) lime was used for laying 1,100 bricks, with ⅜-in. to ½-in. joint; 1 cu. yd. sand was used for laying 2,260 bricks, with ⅜-in. to ½-in. joint.

Cost of Brickwork in Five Buildings for Manufacturing Plant.*— Mr. Sam W. Emerson gives the following record of cost of brickwork in five buildings forming part of a large manufacturing plant. The work was done by the owners hiring their own labor.

All joints in the brickwork were struck both sides, and a first-class job obtained.

On building No. 1 local bricklayers were used at 50 cts. per hour, but for the other buildings city bricklayers at 60 cts. per hour were imported. The latter did better work and more of it, as shown by Table VII.

**Engineering-Contracting*, April, 1906, p. 100.

The hod carriers were developed from local laborers, and were paid 17½ cts. per hour.

Buildings Nos. 1 and 2 were long and low, containing about equal amounts of 9-in. and 13-in. wall.

Buildings Nos. 3 and 4 were higher and had a somewhat larger proportion of 13-in. wall.

Part of the brickwork in No. 4 was started from steel lintels at some distance above the floor line, which explains the high cost of scaffolding.

Building No. 5 was higher and contained more brick than any of the others. It was composed of 13-in. walls, with some 17-in. and 22-in. walls. The heavier walls account in part for the lower cost of laying, but better foremanship had something to do with it.

The scaffolds were erected by carpenters at 20 and 22½ cts. per hour, drawn from other parts of the work when needed.

Handling materials include unloading and hauling brick, sand, lime and cement, and is the average for the job. About one-third of the materials had to be hauled from a switch nearly a mile away, the balance being delivered on a switch run over to the plant site.

The brick were large, so that 918 laid up a "thousand." figuring 14 brick per square foot of 9-in. wall. All openings were deducted.

Brick cost $5.00 and $5.25 per M., f. o. b. the yards; the average cost was $5.08 per M.

No record was kept of the cost of scaffold lumber, as material ordered for other purposes was used and worked up later in wooden buildings.

About two or three weeks after the 60-cent bricklayers started work, the writer, being dissatisfied with the way the work was going, started the practice of preparing careful estimates of the brick laid each week and figuring the cost per 1,000 for bricklayers and helpers.

Within three weeks after the first estimate, the output per bricklayer had increased over 40 per cent, and about 30 per cent increase was maintained.

This illustrates one of the reasons for keeping "up-to-date" cost records.

The cost of the work per 1,000 brick was as follows:

TABLE VII.—LABOR COST PER 1,000 BRICK.

Buildings—Nos.	1.	2.	3.	4.	5.	Av.
Bricklayers,† 60 cts. per hr..	$5.56	$4.49	$4.57	$4.68	$3.68	$4.16
Helpers,* 17½ cts. per hr...	1.95	1.67	2.14	1.95	2.00	1.87
Carpenters,‡ 20 and 22½ cts.	.70	.71	.88	1.15	.67	.77
Handling materials	1.16	1.16	1.16	1.16	1.16	1.16
Total labor	$9.37	$8.03	$8.75	$8.94	$7.51	$7.96

*Hod carriers and mortar men.

†On Building No. 1 bricklayers received 50 cts. per hr.

‡Engaged in building scaffolds.

Note.—Buildings Nos. 1 and 2 were long and low, with about equal amounts of 9-in. and 13-in. walls; Buildings Nos. 3 and 4 had larger proportion of 13-in. wall; Building No. 5 contained more brick than any of the others, and had 13-in. walls, with some 17-in. and 22-in. walls.

COST PER 1,000 BRICK.

Materials:	
Brick, 918, at $5.08	$ 4.67
Brick, freight	1.12
Sand, ½ cu. yd., at $0.46	0.23
Sand, freight	0.13
Cement, 0.44 bbl., at $..	0.88
Lime, 2 bu., at $0.20	0.40
Total, materials	$ 7.43
Total, labor (average)	7.96
Grand total, material and labor, per 1,000 brick	$15.39

As is stated elsewhere in this article, 14 brick were figured as making one square foot of 9-in. wall. This would make 504 bricks, wall measure, per cubic yard. Accordingly, if we divide the figures in the tabulations given above by 2, we will have the cost per cubic yard of brick masonry. On this basis we have:

Materials:	Cost per cu. yd.
459 bricks, at $5.08	$2.33
Freight	.56
¼ cu. yd. sand, at $0.46	.11
Freight	.06
.22 bbl. cement, at $2.00	.44
1 bu. lime, at $0.20	.20
Total, materials	$3.71
Labor:	
Bricklayers	$2.08
Helpers	.93
Carpenters	.39
Handling materials	.58
Total, labor	$3.98
Total, material and labor	$7.69

Cost of Brick Chimneys.—On small chimneys and fireplaces the labor costs 2 to 3 times as much per M. as on plain wall work. A mason (55 cts. per hr) and helper will lay 600 bricks in 9 hrs. The labor costs 30 to 35 cts. per lin. ft. for single-flue chimneys, 8 x 8 ins. square and 4 ins. thick; and 50 cts. per lin. ft. for double-flue chimney. There is a wastage of brick of about 5% where the brick fit, or 10% where cutting is necessary.

Cost of High Brick Chimney Stacks.—With wages of masons at 55 cts. per hr., and where the flue is large enough for men to work from the inside, the cost of laying bricks for chimney stacks, 100 to 125 ft. high, is $12 per M of bricks. In one case a stack 150 ft. high, containing 250,000 bricks, cost $7 per M for labor, wages being as above given.

Cost of Brickwork, Cross-References.—In various sections of this book will be found further data on brick masonry, for which consult the index under "Brickwork."

Cost of Rubble Walls.—Basement walls are commonly made of rubble. The best work requires "two-man rubble," that is, stone too heavy for one man to lift. A common allowance for a lime-

stone rubble wall is 1/3 cu. yd. sand, 1/3 bbl. cement, and 2,800 lbs. stone, per cu. yd. of wall. If lime is used, allow 1/3 bbl. lime. A mason and helper will lay 3 cu. yds. in 8 hrs., so that if wages are 50 cts. per hr. for mason and 25 cts. per hr. for helper, the cost of laying is $2 per cu. yd.

For further data, see the sections on Masonry and Concrete.

Cost of Ashlar.—Ashlar in buildings is estimated by the cubic foot. In ordering "raw stone" (uncut stone) for ashlar, give the quarryman the exact number of cubic feet measured in the wall. He will make allowance for the waste in cutting it.

The cost of Bedford ashlar for the moldings, turrets, etc., in an Omaha building was:

	Per cu. ft.
Raw Bedford	$0.65
Cutting, wages 55 cts. per hr.	1.00
Setting in the building	0.20
Washing and pointing	0.05
Total in place	$1.90

It requires about 1 gal. muriatic acid to wash 500 sq. ft. To wash and point the joints costs 3 cts. per sq. ft.

Cost of Cut Stone Work.*—The walls for the building of the Government Printing Office at Washington, D. C., completed in 1903, were built of red bricks trimmed with red sandstone from a quarry near Longmeadow, Mass. The cost of this stone, ready to set, was as follows:

	Per cu. ft.
Plain ashlar	$1.80-$2.00
Molded courses	2.00- 2.40
Sills	2.00- 2.40
Lintels	1.95- 2.15
Columns	3.00

In computing these prices, all molded and curved or irregular pieces were squared out to the minimum containing rectangular parallelopipedon. The cost of setting, etc., average for all classes, was as follows:

	Per cu. ft.
Handling	$0.133
Setting	.179
Cutting (corrections, etc.)	.018
Pointing	.041
Mortar	.012
Miscellaneous materials	.026
Total	$0.409

The high cost is said to be due to the care with which the joints were calked, and to the fact that there was not enough stone to be placed to justify the purchase of a special plant to handle it. Some of the wages paid for 8-hr. day on this job were as follows: Laborers, $1.50; stone masons, $4; stone cutters, $4.

Engineering-Contracting, Feb. 19, 1908.

Cost of Wood Lathing.—The standard size of wood laths is ¼-in. × 1½ ins. × 4 ft. There is a special lath made 32 ins. in length. Laths are sold by the 1,000 in bundles of 50 or 100 laths per bundle. A common price is $3 per 1,000 laths. It requires 1,500 standard laths to cover 100 sq. yds. Allow 10 lbs. of 3d fine nails for 100 sq. yds. when joists are 16 ins. center to center. Chicago lathers have fixed 1,250 laths as a day's work per man.

The cost per 100 sq. yds. is as follows:

	100 sq. yds.
1,500 laths, at $3 per M	$4.50
10 lbs. nails, at 3 cts.	0.30
Labor, at $3.20 per 8-hr. day	3.84
Total per 100 sq. yds.	$8.64

This is 8.6 cts. per sq. yd. There is no uniformity in practice as to deducting window and door openings from the area lathed.

Cost of Metal Lathing.—There are several makes of wire lathing, as well as expanded metal lathing. For plastering, the Expanded Metal Engineering Co., of New York, furnish two styles of expanded metal lath, in sheets 1⅛ × 8 ft., as follows:

	Lbs. per sq. yd.
"Diamond" lath, Gage No. 24	3.65
"Diamond" lath, Gage No. 26	2.66
"A" lath, Gage No. 24	4.23
"B" lath, Gage No. 27	2.84

The price of these laths ranges from 15 cts. to 20 cts. per sq. yd. The cost per 100 sq. yds. is as follows:

	100 sq. yds.
100 sq. yds., "Diamond" No. 26	$15.00
10 lbs. staples, at 3 cts.	0.30
Labor, at $3.20 per 8-hr. day	3.20
Total per 100 sq. yds.	$18.50

This labor includes the cost of scaffolding, and is based upon some 6,000 sq. yds. of work. It will be noted that the labor cost is 1.2 cts. per lb. of metal.

Cost of Plaster.—Plastering on laths generally requires three coats, occasionally two coats. The first is the scratch coat; the second is the brown coat; the third is the white coat, or finish. On brick walls the scratch coat is generally omitted.

Plaster is made either with lime or with cement plaster. Cement plaster (or wall plaster) usually consists principally of plaster of Paris. Some plasters are made of lime gaged with Portland cement. Whatever kind of lime or plaster is used, sand and hair are mixed with the plaster. The hair is put up in paper bags supposed to contain 1 bu. of hair when beaten up, and supposed to weigh about 7 lbs. Some cement plasters are sold with the proper amount of hair mixed in. Cement plaster is commonly sold in 100-lb. sacks, four sacks making 1 bbl. A common price is 25 cts. per sack.

**Engineering-Contracting*, Dec. 4, 1907.

In making lime plaster, 1 part of lime paste to 2 or 2½ parts of screened sand is used. About 1¾ cu. yds. of sand are required per 100 sq. yds. of three-coat plaster, and about 4 bbls. of lime, or cement plaster, and 2 bu. of hair.

The cost of 100 sq. yds. of three-coat plaster is about as follows:

	100 sq. yds.
1.75 cu. yds. sand, at $1	$ 1.75
3½ bbls. lime, or 9 bu., at 35 cts.	3.15
2 bu. hair, at 40 cts.	0.80
100 lbs. plaster of Paris, at 50 cts.	0.50
Labor, plasterers, at 55 cts. per hr.	15.00
Total, 100 sq. yds., at 21.2 cts.	$21.20

Cost of Plastering.—Mr. R. L. Brooker gives the following average cost of plastering 17 houses in Ohio in 1903. Each house required 500 to 1,000 sq. yds. of plastering.

	Per sq. yd. Cts.
Lath and nails	6.5
Labor lathing	3.0
Materials for 1st coat mortar	3.5
Labor for 1st coat mortar	3.8
Materials for white coat	1.0
Labor for white coat	3.0
Total	20.8

The following materials were required per 100 sq. yds.:

26 bunches of lath.

7 sacks Alabastine (100 lbs. ea.), mixed 1:2.

150 lbs. white coat material (white enamel finish).

In plastering, a man averaged 16 sq. yds. of first coat per hour, although on two jobs the average was 21 sq. yds. per hr. On white coat work, a man averaged 19 sq. yds. per hr., and the best record was 21½ sq. yds. per hr.

The lowest labor cost of lathing was 2¼ cts. per sq. yd.

The plastering was "three-coat" work, the first and second coat being applied at the same time and of the same material, while the third or white coat was not applied till the other coats were dry. The "brown wall" was rodded along angles and base, then darbied, and just before taking a set was floated to an even surface.

Cost of Placing Tile Fireproofing.—Hollow tile used for floors or walls, or for protecting steel beams and columns, is measured by the square foot. It is desirable to purchase it from the manufacturers on the basis of the square foot measured in the work. Where the brick-layers' wages were 45 cts. per hr., the tile work in a four-story hospital cost 5½ cts. per sq. ft. for the labor on the 10-in. and 12-in. tile floors and roof. This does not include the cost of hauling the tile to the building, but it does include the hoisting and delivery of the tile to the masons. The labor cost of 4-in. tile partitions and tile protection for I-beams and columns was 4½ cts. per sq. ft.

Cost of Terra Cotta Brick Fire Proofing.*—Solid brick of porous terra cotta were used for fireproofing the floor arches, girders and column coverings at the U. S. Government printing office, completed in 1903, at Washington, D. C. In connection with the floor arches a very heavy skewback having projecting flanges 1½ ins. thick was designed. The protecting flanges are very heavy and strong, and meet, with a small mortar joint, under the beam. The lower flanges or girders were covered with shoes of the ordinary form, meeting under the girder. They were, however, much heavier than ordinarily used, being solid and 2½ ins. thick. They were filled with mortar and squeezed on, so as to have a solid bearing, and were then wrapped all around with wire lathing and plastered with Portland cement mortar. On top of the shoes, on either side of the girder, was built a 4-in. terra cotta brick wall, the wire lathing being applied before the 4 ins. walls were built. The 4 ins. walls on the sides of the girder were carried to the top flange before the floor arches were built. The latter were then built, abutting at their ends against the upper part of the 4-in. walls, thus bracing them securely in position. The columns were covered with 4-ins. of porous terra cotta brick work built around them. The inside of the column and all space between it and the fire proofing were filled solid with Portland cement concrete. The work was done by contract, the following data being obtained by keeping records of the contractors' work:

From time required to set, it was determined that the girder shoes on the various girders were equivalent to about 8.5 bricks per linear foot. This was a little high for beams smaller than 20 ins., but it was compensated for by increased cost of changing scaffolds, centers, etc., for the smaller girders. The figures of cost do not allow for power for hoisting furnished by the United States, nor for contractor's general expense.

GIRDER COVERINGS OF 33-IN., 30-IN. AND 24-IN. GIRDERS.

Total labor cost:	
Per 1,000 bricks	$12.80
Per linear foot of covering	0.524
Materials, exclusive of the terra cotta and wire netting:	
Per 1,000 bricks	0.85
Per linear foot of covering	0.162
Average day's work per man, bricks	564
Number of bricks per barrel of cement	546

GIRDER COVERINGS FOR GIRDERS 20 INS. AND UNDER.

Labor cost:	
Per 1,000 bricks	$12.80
Per linear foot of covering	0.323
Materials, exclusive of terra cotta and wire netting:	
Per 1,000 bricks	3.40
Per linear foot of covering	0.093
Average day's work per man, bricks	564
Average number of bricks per barrel of cement	615

**Engineering-Contracting*, Dec. 4, 1907.

COLUMN COVERINGS.

Labor Cost:

Per 1,000 bricks	$12.80
Per linear foot of covering	0.46
Average day's work per man, bricks	564
Average number of bricks per barrel of cement	545

In the one linear foot of beam covering (skewbacks) was taken as equivalent to 5.5 bricks in time and labor, data on the work being as follows:

Total labor, per 1,000 bricks	$10.64
Total labor per sq. ft. of floor	0.06
Total materials, except bricks, per 1,000 bricks	3.65
Total materials, except bricks, per sq. ft. of floor	0.021
Average day's work per man, bricks	892
Average number of bricks per barrel of cement	575

The above figures are based on the actual number of bricks laid plus 3 per cent for waste. The average cost of all fireproof construction, excluding ceilings, but including column and girder coverings, and including roof, was 36.4 cts. per square foot, of which 9.5 cts. was labor applied at the building. Some of the wages in force on the work were as follows per 8-hr. day: Laborers, $1.50 to $2; bricklayers, $4 to $4.50.

Cost of Ornamental Terra Cotta Work.*—In the construction of the new U. S. Government printing office at Washington, completed in 1903, 19,100 cu. ft. or 585 tons of ornamental terra cotta was used. All of the ornamental terra cotta was filled solid with concrete and where it projected considerably, as in the main cornice, it was thoroughly tied back with steel anchors. The ornamental terra cotta used was built up of relatively thin webs, like hollow tiles, except that it was built up by hand instead of by being forced through a die. The total cost of the work was as follows; the price given for materials, however, does not include brick or concrete filling:

	Per cu. ft.	Per ton.
Handling	$0.0332	$1.0881
Setting	.1301	4.2513
Cement, etc.	.0243	.7944
Anchors, etc.	.0245	.8010
Total cost of setting	$0.2121	$6.9348
Average price for materials	1.5300	50.0000
Grand total	$1.7421	$56.9348

Some of the wages paid per 8-hr. day during the construction of the building were as follows: Laborers, $1.50; bricklayers, $4 to $4.50.

Cost of Combined Concrete and Tile Floor Construction.†—Reinforced concrete was employed in constructing, during 1908, a 150x50 ft. extension from 8 to 10 stories high to the famous Quebec hotel, the Chateau Frontenac. Structurally the new building consists of a reinforced concrete skeleton covered with brick outside walls, metal roof, etc. The floors were combined clay tile and reinforced concrete con-

**Engineering-Contracting*, Nov. 20, 1907.

†Engineering-Contracting, Aug. 18, 1909.

struction, and columns and girders were of reinforced concrete. Complete records of the cost of the work were kept, but these are not available for publication except for one typical floor, and the cost of this floor is given below.

The typical floor is that located at elevation 187. The slab spans varied from 12 to 16 ft. The tile used were 8 × 12-in. hard terra cotta. The concrete joists were 4 ins. wide, reinforced by one ¾ × 2-in. Kahn bar and one ½-in. cup bar. The joists extended the full depth of the tile and were in one piece, with the 2-in. concrete slab which covered the tile. The floor concrete was a 1-2-4 mixture, and the column concrete was a 1-1-2 mixture. A ¾-in. limestone was used for aggregate. The concrete was machine mixed at basement level and was hoisted to floor level, discharged into a hopper and distributed over the floor by wheelbarrows. The quantities required for the floor were:

Concrete in columns, cu. yds.	43.5
Concrete in floor, cu. yds.	255.8
Reinforcing steel, tons	25.9
Tile, 8 x 12-in., number	28,000
Lumber, forms and staging, ft. B. M.	45,000

The cost of the floor concrete was as follows:

Concrete:	Total.	Per cu. yd.
Materials for 255.8 cu. yds.	$1,445	$5.65
Placing 255.8 cu. yds.	174	0.58
Totals	$1,619	$6.23

This is the cost for the floor slabs and beams above. The cost of the concrete in the columns (43.5 cu. yds.) was $464, or $9.21 per cu. yd. The cost of reinforcement for the whole floor, columns included, was as follows:

Reinforcement:	Total.	Per ton.
29.9 tons steel at $75	$1,943	$75.00
Cartage on steel	21	0.80
Handling and placing steel	130	5.00
Totals	$2,094	$80.80

This gives a cost per cubic yard of concrete for reinforcement of $6.99—or say $7. The cost of forms and staging was as follows:

Forms and Staging:	Total.	Per M. ft.
45 M. ft. B. M. lumber at $22	$990	$22.00
Construction	616	13.70
Totals	$1,606	$35.70

Summarizing, we get the following total cost for concrete, charging everything, except tile work, to concrete:

Item:	Per cu. yd.
Concrete in place	$6.97
Reinforcement	6.99
Forms and staging	5.38
Total	$19.34

The cost of the tile work in the floor slabs was as follows:

Tile Work:	Total.	Per tile.
28,000 tile at 10 cts.	$280	10.00 cts.
Cartage	33	0.12 cts.
Handling and laying	42	0.15 cts.
Totals	$355	10.27 cts.

The total cost of the floor was $6,072, divided into the following percentage items:

Concrete	33 per cent
Steel	35 per cent
Forms	26 per cent
Tile	6 per cent
Total	100 per cent

Costs of Combination Concrete and Tile Floors in Three Buildings.*—The following figures of costs of similar construction are from figures given by Prof. W. K. Hatt, Purdue University, Lafayette, Ind., who was engineer of the work. The work comprised three buildings:

Indiana State Soldiers' Home.—This building is irregular in plan, with two stories, attic and basement. It is constructed of brick and limestone, with reinforced concrete hollow tile floors, each floor covering approximately 7,000 sq. ft. The floor ribs are 4 ins. in width and range in depth from 10 to 6 ins. The rib spans are from 8 to 15 ft. The tile are 12 × 12 ins. of projected area, and the ribs are thus spaced 16 ins. centers in all cases. The thickness of concrete over the tile is 2 ins. Upon this floor is placed a 3-in. cinder concrete, over which there is a ⅞-in. maple flooring upon nailing strips. The floor was designed to hold a live load of 60 lbs. per sq. ft. for the first floor and second floor, and 30 lbs. per sq. ft. live load for the attic floor in addition to cinder filling and wood floor. The ribs were continuous from the side rooms through into the corridor. The concrete was 1:2:4, with a screened gravel aggregate. The gravel and sand contained about 4½ per cent of clay. Reinforcing was plain, round bars of soft steel. Forms consisted of ⅞-in. lagging supported on joists, spaced 24 ins., running between the walls. The steel rods were supported on a large-headed nail driven into the centering, and the wire staple was driven over the bar into the same centering. The channels of the ribs were cleaned of all dirt by blowing out with steam. The tile were kept wet.

The attic floor was of cinder concrete slab construction, 3 ins. thick. Wire fabric of 3 × 12-in. mesh, 3 × 8-in. and Nos. 6 and 10 gage wires, respectively, were used for reinforcing. The cinder concrete was 1:2:4. Cinder was of good quality and screened of all ashes.

Most of the floor construction was during freezing weather and the building was heated. Salamanders were kept burning day and night and the forms were sprinkled to prevent baking the con-

**Engineering-Contracting*, Oct. 13, 1909.

crete, while the exposed surface of the concrete was protected from freezing by tar paper, on which was a layer of manure.

Table VIII. gives the unit cost of the second floor of the Soldiers' Home Hospital. The spans were as follows: Corridor, clear span, 8 ft.; side rooms, clear span, from 10 to 15 ft.

The unit stresses used for the design were as follows: Tension of steel, 16,000 lbs. per sq. in.; compression in concrete, 750 lbs. per sq. in.; bond, 75 lbs. per sq. in.; diagonal tension, 75 lbs. per sq. in. (one bent rod).

TABLE VII.—UNIT COSTS OF SECOND FLOOR, SOLDIER'S HOME HOSPITAL.

	Total.	Per sq. ft. floor.	Per cu. yd. of concrete and mortar.
Tile laying	$108.70	$0.015	$1.40
Steel:			
Bending and placing	36.40		
Cost f. o. b Lafayette	175.00	0.030	2.80
Total	$211.40		
Concrete:			
Cement, 114.5 lbs., $1.75 f. o. b. Lafayette	200.37		
Gravel, 64.24 yds. at $1.10 per yd., hauled and screened	70.66		
Sand, 32.12 yds. at $1.10 per yd., hauled and screened	35.36	0.044	3.96
Total	$306.39		
Mortar:			
Cement, 16.25 bbls., $1.25, f. o. b. Lafayette	28.44		
Sand, 4.4 cu. yds. at $1.10, hauled and screened	4.84	0.005	0.43
Total	$ 33.28		
Labor:			
Wheeling, mixing, hauling, tamping, runs, etc.	255.79	0.036	3.30
Centering:			
Putting up and tearing down	414.40	0.060	5.35
Totals	$1,329.93	$0.190	$17.24

Purdue University Experiment Station Building.—The building is U-shaped, with basement, two stories and attic. The first and second floors were designed for a live load of 100 lbs. per sq. ft., and the attic for a live load of 60 lbs. per sq. ft., in addition to weight of cinder filling and floor. The concrete is 1:2:4; aggregate was screened bank gravel. The sand and pebbles were remixed in specified proportion. Reinforcing was plain, round bars of steel. The floors were supported on girders and columns. The spans varied from 9 to 23 ft.

The centering is composed of 4 × 4-in. posts with 2 × 10-in. chords nailed to them. Upon the chords are joists supporting ⅞-in. lagging. The spacing of the chords, posts and joists varied accord-

ing to the weight of the floor supported. On the lagging tiles are placed with a clearance of not less than 4 ins. from all walls and girders and spaced 17 ins. centers, thus making a 5-in. rib. In laying these tile, hard-burned, small tile were placed together, and soft-burned, large tile together, thus assuring a rib of even width. The

TABLE IX.—UNIT COSTS FIRST FLOOR EXPERIMENT STATION.

	Total.	Per sq. ft. of floor area.	Per cu. yd. of concrete and mortar.
Tile:			
Laying	$ 43.20		
Hoisting	129.60		
Cost f. o. b. Lafayette	567.85	$0.0587	$3.47
Total	$740.65		
Steel:			
Bending and placing	255.69		
Cost, f. o. b. Lafayette	582.00	0.0664	3.92
Total	$837.69		
Concrete, 1,961 yards:			
Cement, 308 bbls. at $1.17 f. o. b. Lafayette	360.36		
Sand, $1 per yd., hauled and screened	86.30		
Gravel, $1 per yd., hauled and screened	172.60	0.0490	2.90
Total	$619.26		
Mortar, 178 yards:			
Cement, $1.17 f. o. b. Lafayette	42.70		
Sand, $1 per yd, hauled and screened	17.80	0.0048	0.28
Total	$ 60.50		
Labor:			
Wheeling, mixing, hoisting, tamping, runs and dumping	542.50	0.0436	2.53
Centering:			
Let by contract at $12 per 1,000; 67,600 used (labor only)	811.20	0.0642	3.80
Superintendence	330.00	0.0261	1.54
Total	$3,941.80	$0.3122	$18.44

rods were held in place by nails and staples and were continuous from one panel to another. Before any concrete was deposited in the ribs a 1:3 cement mortar was placed in the bottom of the channel and brought to the level of the middle of the rod. Great care was exercised in cutting the concrete in between the rods and against the faces of the tile. The concrete was very wet, so that it would keep an even surface in the wheelbarrow, but yet would support the pebbles on the surface.

A batch of concrete in the mixer was received in a bucket and hoisted to a large box on the floor, and taken out in barrows to be dumped.

TABLE X.—UNIT OF COSTS OF SECOND FLOOR, EXPERIMENT STATION.

	Total.	Per sq. ft. of floor area.	Per cu. yd of concrete and mortar.
Tile:			
Hoisting	$125.00		
Laying	48.20		
Cost f. o. b. Lafayette	593.62	$0.0607	$3.42
Total	$766.82		
Steel:			
Bending and placing	178.73		
25.5 tons at $30, f. o. b. Lafayette	765.00	0.0745	4.22
Total	$943.73		
Concrete, 214 yards:			
Cement, 336.5 bbls. $1.17, f. o. b. Lafayette	393.70		
Sand, 94.16 yds., at $1, screened and hauled	94.16		
Gravel, 188.32 yds	188.32	0.0535	3.02
Total	$676.18		
Mortar, 9.5 yards:			
Cement, 26 bbls. at $1.16, f. o. b. Lafayette	30.40		
Sand, 9.5 yds. at $1, screened and hauled.	9.50	0.0036	0.18
Total	$ 39.90		
Labor:			
Wheeling, mixing, tamping, dumping runs	461.38	0.0364	2.06
Superintendence	145.00	0.0115	0.65
Centering:			
Set by contract (approximately)	600.00	0.0475	2.68
Total	$3,633.01	$0.2877	$16.22

The first floor was laid during freezing weather. To prevent freezing, salamanders were kept burning day and night and the concrete was covered with a heavy layer of straw.

The labor for the concrete was paid at a rate of 20 cts. an hour. The unit cost for the first and second floors of the experiment station are given by Tables IX and X, as furnished by H. A. Wortham, inspector on the work. Note that these floors cost on an average of about 30 cts. per square foot.

The unit stresses used were as follows: Tension in steel, 16,000 lbs. per sq. in.; compression in concrete, 750 lbs. per sq. in.; bond on steel, 75 lbs. per sq. in.; diagonal tension without stirrups, but with one bent rod, 75 lbs. per sq. in.

The external moments were figured ⅛ W. L., both at the center and over supports. The length of span was between centers of the bearings. This design is conservative, and, in the belief of the writer, might be cut down perhaps 25 per cent with safety.

Shrinkage stresses at the surface of the floors are taken up by ¼-in. wire.

Cost of Bituminous Concrete for a Mill Floor.*—In laying tar

**Engineering-Contracting,* Aug. 14, 1907.

concrete base for wood covered mill floors, the common practice is to use a mixture of steam cinders aggregate and coal tar binder, and to mix the materials by hand. A departure from this practice is recorded by Mr. C. H. Chadsey, Construction Engineer, Northern Aluminum Co., Ltd., Shawinigan Falls, P. Q., Canada, in laying 17,784 sq. ft. of mill floor. A sand, broken stone and tar mixture was used and the mixing was done with a Ransome mixer. The apparatus used and the mode of procedure followed were as follows:

Two parallel 8-in. brick walls 26 ft. long were built 4 ft. apart and 2½ ft. high to form a furnace. On these walls at one end was set a 4x6x2 ft. steel plate tar heating tank. Next to this tank for a space of 4x8 ft. the walls were spanned between with steel plates. This area was used for heating sand. Another space of 4x8 ft. was covered with 1¼ in. steel rods arranged to form a grid; this space was used for heating the broken stones. The grid proved especially efficient, as it permitted the hot air to pass up through the stones, while a small cleaning door at the ground allowed the screenings which dropped through the grid to be raked out and added to the mixture. A fire from barrel staves and refuse wood built under the tank end was sufficient to heat the tar, sand and stone.

For mixing the materials a Ransome mixer was selected for the reason that heat could be supplied to the exterior of the drum by building a wood fire underneath. This fire was maintained to prevent the mixture from adhering to the mixing blades, and it proved quite effective, though occasionally they would have to be cleaned with a chisel bar, particularly when this aggregate was not sufficiently heated before being admitted to the mixture. A little "dead oil" applied to the discharge chute and to the shovels, wheelbarrows and other tools effectually prevented the concrete from adhering to them.

The method of depositing the concrete was practically the same as that used in laying cement sidewalks. Wood strips attached to stakes driven into the ground provided templates for gaging the thickness of the base and for leveling off the surface. The wood covering consisted of a layer of 2-in. planks, covered by matched hardwood flooring. In placing the planking, the base was covered with a ¼-in. layer of hot pitch, into which the planks were pressed immediately, the last plank laid being toe-nailed to the preceding plank just enough to keep the joint ight. After a few minutes the planks adhered so firmly to the base that they could be removed only with difficulty. The hardwood surface was put on in the usual manner.

The prices of materials and wages for the work were as follows:

Pitch, bulk, per lb.	$ 0.0075
Gravel per cu. yd.	1.50
Spruce sub-floor, per M. ft. B. M.	15.00
Hardwood surface, per M. ft. B. M.	33.00
Laborers per 10-hour day	1.50
Foreman, per 10-hour day	4.00
Carpenters, per 10-hour day	2.00

At these prices and not including a small administration cost or the cost of tools and plant, the cost of the floor consisting of 4½ ins. of concrete, 2 ins. of spruce sub-flooring and ⅞ in. hardwood finish was as follows:

	Per sq. ft.
Pitch	$0.04
Gravel	0.02
Spruce, for sub-floor	0.03
Hardwood for surfacing	0.035
Labor, mixing	0.03
Labor, laying	0.015
Carpenter work	0.025
Total per sq. ft.	$0.195

Cost of Passenger Stations.—In the *Railroad Gazette,* Sept. 16, 1904, p. 350, photographs are given of a passenger station of the Santa Fe at Oakland, Calif. It is 204 ft. long, including arcades, and 54 ft. wide, total 11,000 sq. ft., and its cost was $12,000. The main part is two stories high. It has arcades 12 ft. wide running entirely around it. The building is Spanish mission style, built of steel lath covered with concrete and with red tile roof.

A one-story brick passenger station built in 1898 at Quincy, Ill., for the C. B. & Q. R. R., cost $75,000, or $4.27 per sq. ft. It is 58 x 304 ft., and has a tower, 20 ft. square at the roof level, rising to a height of 150 ft. The walls of the station are of red pressed brick, with trimmings of sandstone and terra cotta. The walls are 22 ft. high. The roof is of Spanish tile, with a pitch of 30°. The interior finish is an enameled brick wainscoting, and plastered walls and ceiling. The waiting room (54 x 70 ft.) has a marble tile floor, and the other rooms have mosaic tile floors.

Cost of Four Frame Depots*.—This is the first of a series of articles that we shall publish on the cost of railway buildings. While they are typical railway structures, still the cost data will be found equally valuable in estimating the costs of buildings erected for other purposes.

It is a fact not generally known that the labor cost of framing and erecting plain buildings averages from $10 to $15 per 1,000 ft. B. M. This fact will be clearly brought out in these articles, and it will be of great assistance to anyone who is called upon to estimate the cost of a plain frame building. Wages will be given in each case, but the reader is cautioned against supposing that an increase in wages necessarily involves a corresponding increase in cost. A high priced carpenter is usually more efficient than a low priced carpenter, the very fact that he is high priced often being evidence in itself that he is correspondingly more competent than the low priced man. A contractor who pays $3.50 a day for carpenters will usually get more work done for the money than will a railway company that pays $2.50 a day for its "company carpenters." Railways have a policy of paying very low wages, under

---

**Engineering-Contracting,* Aug. 28, 1907.

the mistaken idea that they are economizing thereby. In consequence, they usually secure lazy or incompetent day workers. Perhaps, with their present lack of system in keeping costs of construction, the railways would gain nothing by employing higher priced men.

The work that we are about to describe was done by "company forces," carpenters receiving $2.50 for 10 hours. As is usually the case in day labor jobs, the men were very slow.

The method of summarizing the costs of buildings is our own. Records kept by railways are usually so jumbled up as to be of no use in comparing the costs of similar structures or in ascertaining whether the cost of any particular structure has been reasonable or not. This is largely because the engineering department is not in charge of building construction, or, if it is in charge, the engineers take little interest in work which does not seem to be engineering. There is crying need for cost analysis engineering in the management of all building construction, but particularly on railways.

The cost of those plain frame depots may be conveniently distributed under seven headings:

Lumber.
Shingles.
Millwork.
Hardware.
Paint.
Masonry.
Labor.

The first six items cover the materials. The labor item can be subdivided to suit each particular kind of work.

The weight of each building of standard design should be estimated, so that the items of freight and team haulage can be accurately predicted, but this is rarely done by railway companies.

The number of square feet of ground floor area should be stated, and the cost of each building reduced to costs per square foot, both in dollars and cents and in percentages.

Cost of a 24 x 60 Ft. Depot.—This was a small combination passenger and freight depot, of very plain design, without a masonry foundation and without plastering. The building was one story, 24x60 ft., surrounded by a wooden platform in front and ends, and a cinder platform extension.

This depot had an area of 1,440 sq. ft., exclusive of the platform.

Weight.	Lbs.
30 M. at 3,300 lbs.	99,000
20 M. shingles at 150 lbs.	3,000
Millwork	1,000
Hardware	1,600
1,100 brick	6,000
Total, 55 tons	110,600

Lumber.

8,025 ft. B. M., at $8.00	$ 64.20
12,800 ft. B. M., No. 2 com. S. I. S., at $8.50	108.80
1,400 ft. B. M., 1 in. oak, at $10.00	14.00
3,000 ft. B. M., ¾ x 8 ft. to 18 ft., at $14.00	42.00
2,700 ft. B. M., No. 2 D. siding, at $14.40	38.88
1,100 ft. B. M., No. 3 flooring, at $12.00	13.20
832 ft. B. M., No. 1 flooring, at $19.10	15.89
30,057 ft. B. M., total lumber, $13.23 av.	$296.97

Shingles.

20 M. shingles, at $1.10	$ 22.00

Millwork.

900 lin. ft. miscel. moulding, at 1c.	$ 9.00
225 lin. ft. 5 in. crown moulding, at 3c.	6.75
1 transom, 3 doors, 9 windows	24.00
Frames for doors and windows	16.00
Total millwork	$ 55.75

Hardware.

8 rolls tar paper at 75c	$ 6.00
900 lbs. nails, at 2½c.	22.50
Locks, knobs, hinges, etc.	9.00
Total hardware	$37.50

Paint.

Paint, 23 gals. at 70c	$16.10

Masonry.

Brick, 1,100, at $8.00	$ 8.80

Labor.

Building depot.	
38 days foreman, at $80.00 per mo.	$ 98.38
87 days carpenter, at $2.50	217.50
51.2 days helper, at $1.75	90.05
176.2 days total, at $2.32 average	$406.38
Putting up ladders.	
2 days carpenter, at $2.50	$ 5.00
Painting depot.	
14 days helper, at $1.75	$ 24.50
Building chimney.	
4 days mason, at $4.00	$ 16.00
Filling cinders in platform.	
2 days section foreman, at $50.00 per mo.	$ 3.20
6 days labor, at $1.05	6.30
8 days labor, total	$ 9.50
Tools	$ 38.50

Summary:

Materials.	Total.	Per cent.
30,057 ft. B. M., at $13.23	$296.97	33.2
20 M. shingles, at $1.10	22.00	2.4
Millwork	55.75	6.1
Hardware	37.50	4.1
23 gals. paint, at 70c	16.10	1.8
1,100 brick, at $8.00	8.80	1.0
Total materials	$437.12	48.6

Labor.		
176.2 days labor building, at $2.32	$406.38	45.3
2 days labor, put up ladders, at $2.50	5.00	0.6
14 days labor, painting, at $1.75	24.50	2.8
4 days labor, building chimney, at $4.00	16.00	1.8
8 days labor, filling cinders, at $1.20	8.50	0.9
Total labor	$460.38	51.4
Total materials and labor	$897.50	100.0
Freight 55 tons, 200 mi., ½c ton mile	$ 55.00	
	$952.50	
Tools (excessive in this case)	38.50	
Grand total	$990.00	

	Per. sq. ft.	Per cent.
Materials	$0.304	44.2
Labor	0.319	46.5
Freight	0.038	5.5
Tools	0.027	4.0
Total	$0.688	100.00

It will be noted that the price of lumber was very low.

The total labor was $460, which is practically $15 per 1,000 ft. B. M. in the depot and platform. If we exclude the labor of building the chimney, painting the depot and spreading the cinder platform, the labor cost $406, or about $13 per 1,000 ft. B. M., yet some time was lost by the crew waiting for lumber to arrive. This lost time should have been recorded, but was not.

Cost of Another 24 x 60 Ft. Depot.—This depot was similar to the last, except that 7,200 ft. B. M., of second-hand car sills (8x16 ins.), were used for posts and stringers of the platform. Grading of the depot grounds was an unusually expensive item.

Lumber.	
8,000 ft. B. M., at $8.50	$ 68.00
7,200 ft. B. M. (8 in. x 16 in.) second-hand, at $4.00	28.80
6,400 ft. B. M., S. I. S., at $10.00	64.00
8,900 ft. B. M., S. I. S., 1 in., at $12.00	106.80
1,050 ft. B. M., com. floor, at $12.50	13.12
3,600 ft. B. M., com. ceiling, at $12.50	45.00
900 ft. B. M., clear floor, at $21.00	18.90
2,600 ft. B. M., drop siding No. 2, at $21.00	54.60
300 ft. B. M., com. ceiling, at $15.00	4.50
38,950 ft. B. M., total lumber	$403.72
Shingles.	
23 M. shingles, at $1.60	$ 36.80
Millwork.	
1,200 lin. ft. molding, at ¾c av.	$ 9.00
Doors and windows and frames	70.00
Total millwork	$ 79.00
Hardware.	
5 rolls tar paper at 70c.	$ 3.50
Locks, knobs, hinges, etc.	6.00
1,400 lbs. nails, at 2¼c.	35.00
Total hardware	$ 44.50

Paint.

34 gals. paint, at 75c	$ 25.50
16 gals. boiled oil and turp	9.00
10 gals. Roger's black paint, at $2.00	20.00
Total paint	$ 54.50

Masonry.

1 M. brick	$ 8.00

Labor.

Unloading lumber.	
2 days, carpenter, at $2.50	$ 5.00
7 days, helper, at $2.00	14.00
9 days, total. av. at $2.10	$ 19.00
Building and painting depot.	
33 days, foreman, at $80.00 per mo	$ 86.66
140.2 days, carpenter, at $2.50	350.50
74.1 days, helper, at $2.00	148.20
247.3 days, total, av. at $2.41	$585.36
Grading depot grounds.	
5 days, section foreman, at $65.00 per mo	$ 10.45
153 days, section men, at $1.10	168.45
158 days, total grading	$178.90
Tools	$ 26.00

Summary:

Materials.	Totals.	Per cent.
38,950 ft. B. M., lumber	$ 403.72	32.7
23 M. shingles, at $1.60	36.80	3.0
Millwork	79.00	6.3
Hardware	44.50	3.6
44 gals. paint, and 16 gals. oil and turp.	54.50	4.4
1,000 brick	8.00	0.6
Total materials	626.52	51.0
Labor.		
9 days, unload lumber, at $2.11	$ 19.00	1.6
247.3 days, building, at $2.41	585.36	47.4
Total labor	$ 604.36	49.0
Total materials and labor	$1,230.88	100.0
Freight, 70 tons at $1.00	70.00	
Tools	26.00	
Grading depot grounds	178.90	
Grand total	$1,505.78	

	Per sq. ft.	Per cent.
Materials	$0.436	41.7
Labor	0.420	40.2
Freight	0.049	4.7
Tools	0.016	1.6
Grading	0.124	11.8
Total	$1.045	100.0

It will be noted that the labor on the depot, exclusive of grading the grounds, amounted to $604. This is a trifle more than $15.50 per 1,000 ft. B. M.

It will be noted that the paint for this depot cost four times what paint cost for the other depot, indicating the necessity of so

classifying costs as to enable comparisons to be quickly made with a view to discovering "leaks."

Cost of a 30 x 48 Ft. Depot.—This depot has the same area, 1,440 sq. ft., as those previously described, but is wider and shorter. The labor of building this depot cost $542, which is equivalent to a little more than $13 per 1,000 ft. B. M.

Weight.	Lbs.
41 M. at 3,300 lbs.	135,300
21 M. shingles, at 150 lbs.	3,150
Millwork	1,000
Hardware	1,600
1,000 brick	6,000
6 bbls. cement	2,400
Weight, 75 tons	149,450
Lumber.	
10,255 ft. B. M., at $ 7.00	$ 71.79
10,940 ft. B. M., S. I. S. 2E, at $7.50	82.05
3,920 ft. B. M., S. I. S., at $7.50	29.40
4,600 ft. B. M., No. 2 boards, at $11.90	54.74
2,800 ft. B. M., 1x6 siding, at $14.00	39.20
1,100 ft. B. M., 1x4 flooring, D. M., at $19.00	20.90
1,700 ft. B. M., 2x6 selected, D. M., at $8.50	14.45
139 ft. B. M., S. 4 S., No. 2 clr., at $17.00	2.36
568 ft. B. M., S. I. S., at $10.00	5.68
200 ft. B. M., S. 4 S., at $19.00	7.28
4,437 ft. B. M., 8 in. x 16 in., S. H., at $4.00	17.75
40,729 ft. B. M., total av., at $8.50	$345.60
21 M. shingles, at $1.75	$ 36.75
Millwork.	
1,380 lin. ft. molding at ¾c	$ 10.35
Windows, doors and frames	48.00
Total millwork	$ 58.35
Hardware.	
11 rolls tar paper at 65c	$ 7.15
750 lbs. nails at 2¼c	16.90
Locks, knobs, hinges, etc.	5.60
Miscellaneous	9.60
Total hardware	$ 39.25
Paint.	
30 gals. outside paint at 60c	$ 18.00
20 gals. inside paint at 85c	17.00
Total paint	$ 35.00
Masonry.	
1,000 brick at $9.00	$ 9.00
24 sacks cement at $1.00	24.00
3 sacks lime at 60c	1.80
Total masonry	$ 34.80
Labor.	
Unloading material.	
1 day foreman at $80.00 per mo.	$ 2.67
5 day carpenters at $2.50	12.50
10 day helpers at $2.00	20.00
16 Total av. $2.20	$ 35.17

Putting in foundation.	
5 day carpenters at $2.50	$ 12.50
4 day helpers at $2.00	8.00
9 Total av. $2.30	$ 20.50
Building depot.	
27 days, foreman, at $80.00	$ 69.77
87.5 days, carpenter, at $2.50	218.75
50.5 days, helper, at $2.00	101.00
165 days, total av. $2.36	$389.52
Painting depot.	
6 days, carpenter, at $2.50	$ 15.00
9 days, helper, at $2.00	18.00
15 days, total av. $2.20	$ 33.00
Excavating for platform and privy.	
9 days, helper, at $2.00	$ 18.00
Unloading cinders and build cinder platform.	
18.5 days, helper, at $2.00	$ 37.00
Building chimney.	
1.5 days, bricklayer, at $3.50	$ 5.25
2.0 days, helper, at $2.00	4.00
3.5 days, total av. $2.70	$ 9.25
Tools	$ 60.00

Summary:

Materials.	Totals.	Per cent.
40,729 ft. B. M., at $8.50	$ 345.60	31.8
21 M. shingles at $1.75	36.75	3.4
Millwork	58.35	5.3
Hardware	39.25	3.5
Paint	35.00	3.2
Masonry	34.80	3.2
Total	$ 549.75	50.4
Labor.		
16 days, unloading, $2.20	$ 35.17	3.2
9 days, put in foundation, at $2.30	20.50	1.9
165 days, build depot, $2.36	389.52	35.8
15 days, paint depot, $2.20	33.00	3.0
9 days, excavation, $2.00	18.00	1.6
18.5 days, build cinder platform, $2.00	37.00	3.3
3.5 days, build chimney, $2.70	9.25	0.8
Total labor	$ 542.44	49.6
Total materials and labor	1,092.19	100.0
Tools (excessive)	60.00	
Total	$1,152.19	
Freight, 75 tons, 200 mi., at ½c ton mi.	75.00	
Grand total	$1,227.19	

	Cost per sq. ft.	Per cent.
Materials	$0.385	44.8
Labor	0.378	44.0
Tools	0.042	5.0
Freight	0.052	6.2
Total	$0.857	100.0

Cost of a 30 x 60 Ft. Depot.—This depot is of the same general type as the others, but larger, having an area of 1,800 sq. ft. It will be noted that it contains a large amount of second-hand car sills (15,200 ft. B. M.), used in building the platform. The labor cost was $714, or nearly $12 per 1,000 ft. B. M. The labor of painting the depot was very high. The cost of the paint was not $20, yet the labor of painting was nearly $70.

Weight.	Lbs.
61,000 ft. B. M., at 3,300	201,000
26 M. shingles, at 150	3,900
Millwork	1,000
Hardware	1,600
Brick	6,000
Stone	21,600
Total weight, 118 tons	235,100

Lumber.	
8,108 ft. B. M., at $8.50	$ 51.92
6,912 ft. B. M., at $8.50	58.75
1,440 ft. B. M., S. I. E., $8.50	12.24
3,700 ft. B. M., boards, $8.50	31.45
4,300 ft. B. M., S. I. S., $9.00	38.70
9,189 ft. B. M., S. I. S., $9.00	82.70
10,900 ft. B. M., No. 2 floor, ceiling and siding, $18.50	201.65
408 ft. B. M., No. 2, S. 4 S., $26.00	10.63
836 ft. B. M., S. 1. S., $25.00	20.90
70 ft. No. 2, S. 4 S., $1.00	2.17
15,200 ft. B. M., 8 in. x 16 in., S. H. (for platform), $4.00	60.80
61,063 ft. B. M., total av. $8.73	$531.91
Shingles.	
26 M. shingles, $1.72	$ 45.00
Millwork.	
1,540 ft. moulding at 1c	$ 15.40
6 doors, 9 windows and frames	60.60
Total millwork	$ 76.00
Hardware.	
11 rolls bldg. paper, 57c	$ 6.27
900 lbs. nails, 2½c	22.50
Locks, knobs, hinges, etc	21.00
Total hardware	$ 49.77
Paint.	
13 gals. O. B. paint, 50c	$ 6.50
14 gals. boiled oil, 37½c	5.25
16 gals. inside paint, 50c	8.00
Total paint	$ 19.75
Masonry.	
1,000 bricks, $9.00	$ 9.00
144 cu. ft. undressed stone, 70c	100.80
1½ bbls. lime, 85c	1.28
Total masonry	$111.08

Labor.

Unloading material.

6.5 days, carpenter, $2.50	$ 16.25
17.7 days, section men, $1.15	20.35
24.2 days, total av. $1.50	$ 36.60

Trucking* lumber.

1 day, foreman, at $80.00 per mo.	$ 2.85
5 days, carpenter, $2.50	12.50
29.5 days, helper, $2.00	59.00
35.5 days, total av. $2.09	$ 74.08

*Note.—Track was a long distance from depot.

Clearing snow off timber.

3 days, helper, at $2.00	$ 6.00

Erecting depot.

21 days, foreman, $80.00 per mo.	$ 54.19
114 days, carpenter, $2.50	285.00
24 days, helper, $2.00	48.00
159 days, total av. $2.44	$387.19

Painting depot.

2 days, foreman, $80.00 per mo.	$ 5.16
1 day, carpenter, $2.50	2.50
31 days, helper, $2.00	62.00
34 days, total av. $2.05	$ 69.66

Unloading cinders.

10.8 days, section foreman, $55.00	$ 19.19
7.0 days, section laborers, $1.20	7.95
15.1 days, section laborers, $1.05	15.90
32.9 Total av. $1.30	$ 43.04

Building platform.

7 days, foreman, $80.00	$ 18.07
17.6 days, carpenter, $2.50	44.00
11.2 days, helper, $2.00	22.40
35.8 days, total av. $2.36	$ 84.47

Building privy.

5.4 days, carpenter, $2.50	$ 13.50
Tools	$ 51.00

Summary:

Materials.	Totals.	Per cent.
61,063 ft. B. M., $8.73	$ 531.91	34.4
26 M. shingles, $1.72	45.00	2.9
Millwork	76.00	4.9
Hardware	49.77	3.2
Paint	19.75	1.3
Masonry	111.08	7.2
Total	$ 833.51	53.9

Labor.

24.2 days, unload, $1.50	$ 36.60	2.4
35.5 days, trucking, $2.09	74.08	4.7
3.0 days, clear snow, $2.00	6.00	0.4
159.0 days, erect depot, $2.44	387.19	25.0
34.0 days, paint depot, $2.05	69.66	4.5
32.9 days, unload cinders, $1.30	43.04	2.8
35.8 days, build platform, $2.36	84.47	5.5
5.4 days, build privy, $2.50	13.50	0.8
Total	$ 714.54	46.1
Total materials and labor	$1,548.05	
Tools	51.00	
Total	$1,598.05	
Freight, 118 tons	118.00	
Grand total	$1,716.05	

	Cost per sq. ft.	Per cent.
Materials	$0.463	48.6
Labor	0.397	41.6
Tools	0.028	2.9
Freight	0.066	6.9
Total	$0.954	100.0

Cost of 57 Frame Depots.—The following data relate to a rather cheap class of railway stations built in the Pacific Northwest, by company labor. Carpenters received $2.50 per 10. hr. day. Lumber was exceedingly cheap, hence the cost of materials is not typical. I have charged the entire cost of labor against the lumber, as that enables us to compare costs in terms of the M. ft. B. M., which is the best single unit for such comparisons.

The average cost of five, first class, combination, one-story depots (24 x 75 ft.) was as follows per depot:

	Total.	Per sq. ft.
Materials	$1,450	$0.80
Labor	927	0.52
Total	$2,377	$1.32

There were 69 M. (including platforms) in each depot, hence the labor cost was $13 per M.

The average cost of three, third class, combination, one-story depots (24 x 55 ft.) was as follows per depot:

	Total.	Per sq. ft.
Materials	$ 964	$0.75
Labor	726	0.55
Total	$1,690	$1.30

There were 39 M. (including platforms) in each depot, hence the labor cost was $18 per M.

The average cost of 18 fourth class, combination, one-story depots (16 x 48 ft.) was as follows per depot:

	Total.	Per sq. ft.
Materials	$480	$0.62
Labor	320	0.42
Total	$800	$1.04

There were 20 M. (including platforms) per depot, hence the labor cost was $16 per M.

The average cost of 15 fourth class, combination, one-story depots (16 x 68 ft.) was as follows per depot:

	Total.	Per sq. ft.
Materials	$ 700	$0.64
Labor	533	0.49
Total	$1,233	$1.13

There were 26 M. per depot, hence the average labor cost was $20 per M.

The average cost of five, second class, combination, two-story depots (24 x 59 ft.) was as follows per depot:

	Total.	Per sq. ft.
Materials	$1,480	$1.04
Labor	1,150	0.81
Total	$2,630	$1.85

There were 71 M. per depot, hence the average labor cost was $16 per M.

The average cost of 11 third class, combination, two-story depots (24 x 55 ft.) was as follows per depot:

	Total.	Per sq. ft.
Materials	$1,270	$0.96
Labor	1,000	0.77
Total	$2,270	$1.73

There were 51 M. per depot, hence the average labor cost was nearly $20 per M.

The Cost of Five Frame Section Houses.*—In this issue we give the cost of five frame section houses. These were built in the northwest and were three room houses of very cheap construction, the type known in that section as "Jap houses." The work was done by company forces. As is customary for day labor work, nothing has been allowed for superintendence and general office expenses, as would have been the case if the houses had been built by contract.

The three room houses were 16x24 ft., having 384 sq. ft. of room space. The bill of material for each house was as follows:

*_Engineering-Contracting_, Sept. 11, 1907.

Bill of Material for 16 x 24 Section House.

	Ft. B. M.
44 pcs. 2x12—2	176
5 pcs. 6x6—16	240
18 pcs. 2x8—16	384
18 pcs. 2x4—16	192
36 pcs. 2x4—12	288
2 pcs. 1x6—14	14
70 pcs. 2x4—8	373
24 pcs. 2x4—14	192
16 pcs. 2x4—16	171
4 pcs. 2x2—12	16
1,940 ft. com. boards, s1s	1,940
95 pcs. 1x10—10, s1s	792
1 pcs. 2x12—12, s1s	24
6 pcs. 1x6—14, s1s	42
4 pcs. 1x12—14, s1s	56
8 pcs. 1x6—12, s1s	48
1,700 ft. 1x6 D. and M., s1s	1,700
270 ft. 1x6 D. and M., s2s	270
95 pcs. 1x3—10	237
7 pcs. 2x4—12, s4s	56
11¾x¾x12, ¼ rd	132
2 pcs. 2x4—14, s4s	19
4 pcs. 4x4—6	32

5 M. shingles.
15 pcs. ⅞x1¾—16 cover moulding.
18 pcs. 8x10 flashing tin.
1 door 2.10x6.10x1⅛, 4 P. and G.
1 door frame, as above.
2 doors 2.8x6.8x1⅛, 4 P. and G.
4 windows 10x16—1⅜, 12 lts.
4 window frames.
850 brick.
10 lbs. 20d nails.
100 lbs. 8d nails.
25 lbs. shingle nails.
10 sash spring bolts.
8 prs. wrought butts.
3 doz. 1-in. No. 8 screws.
1 sack lime.
2 rolls tarred paper.
3 rim locks and knobs complete.
5 gals. outside body paint.
1 gal. outside trimming paint.
5 gals. inside body paint.
1 gal. inside trimming paint.

The estimated weight is:

	Pounds.
7,200 ft. B. M. at 3,300 lbs.	23,760
5 M. shingles at 150 lbs.	750
Millwork	500
Hardware and paint	400
Brick	2,100
Total	27,510

For practical purposes the weight can be considered as 14 tons. The cost of materials and labor for each house was:

HOUSE No. 1.

Lumber.

2,046 ft. B. M., $7.50	$15.35
2,902 ft. B. M., s1s, $8	23.22
2,207 ft. B. M., 1x6, D. and M., $12	26.48
100 ft. B. M., $9	.90
7,255 ft. B. M., total, $9.10 (av.)	$65.95
5 M. shingles, Star S, $1.35	6.75

Millwork.

Moulding	$ 2.50
3 doors and 4 windows	26.46
Total millwork	$28.96

Hardware.

2 rolls tarred paper, 85 cts.	$ 1.70
135 lbs. nails	4.94
Locks, hinges, etc.	4.82
18 pcs. 8x10 flashing tin	.48
Total hardware	$11.94

Paint.

5 gals. o. s. body paint at 75 cts.	$ 3.75
1 gal. o. s. trimmings at 70 cts.	.70
5 gals. i. s. body paint at 80 cts.	4.00
½ gal. i. s. trimmings at 85 cts.	.43
Total paint	$ 8.88

Masonry.

350 brick at $7.50	$ 2.62

Labor.

Engineering	$ 4.05
Building section house.	
16.5 days, carpenter, at $2.50	$41.25
2.0 days, bridgeman, at $2.25	4.50
18.5 days, total, at $2.47	$45.75
Building flue.	
1 day, bridgeman, at $2.25	$ 2.25
1 day, helper, at $1.75	1.75
Total	$ 4.00
Painting.	
4 days, foreman, at $2.50	$10.00
Tools	4.50

Summary:

Materials.

	Totals.	Pct.
7,255 ft. B. M. lumber at $9.10	$ 65.95	29.0
5 M. shingles at $1.35	6.75	2.9
Millwork	28.96	12.8
Hardware	11.94	5.2
Paint	8.88	3.9
Masonry, 350 brick, $7.50	2.62	1.1
Total materials	$125.10	54.9

Labor.

Engineering	$ 4.05	1.8
18.5 days building house, $2.47	45.75	20.1
2 days building flue, $2	4.00	1.8
4 days painting, $2.50	10.00	4.4
Total labor	$ 63.80	28.1
Total material and labor	188.90	83.0
Tools	4.50	2.0
Freight, 14 tons (excessive chg.)	33.44	15.0
Total	$226.84	100.0
	Per sq. ft.	Per cent.
Materials	$0.326	55.2
Labor	0.167	28.3
Tools	0.012	2.0
Freight	0.085	14.5
Total	$0.590	100.0

HOUSE NO. 2.

Labor.

Unloading material.	
2 days, carpenter, at $2.50	$ 5.00
Building house.	
16.5 days, carpenter, at $2.50	41.25
Building flue.	
1.3 days, mason, at $3	3.90
Painting.	
1 day, foreman, at $2.50	2.50
3 days, helper, at $1.75	5.25
Total labor	$ 7.75
Tools	3.65

Summary:

Materials.

	Total.	Pct.
7,255 ft. B. M. lumber at $9.10	$ 65.95	30.9
5 M. shingles at $1.35	6.75	3.1
Millwork	28.96	13.5
Hardware	11.94	5.6
Paint	8.88	4.1
Masonry, 350 brick, $7.50	2.62	1.2
Total materials	$125.10	58.4
Labor.		
18.5 days, building house, at $2.50	$ 46.25	21.7
1.3 days, building flue, at $3	3.90	1.8
Painting	7.75	3.6
Total labor	$ 57.80	27.1
Total material and labor	182.90	85.5
Tools	3.65	1.7
Freight	27.31	12.8
Total	$213.86	100.0
	Per sq. ft.	Per cent.
Materials	$0.326	58.7
Labor	0.150	27.1
Tools	0.009	1.6
Freight	0.071	12.6
Total	$0.556	100.0

House No. 3.

Labor.

Unloading materials.

2 days, carpenter, at $2.50	$ 5.00
Building house.	
16 days, carpenter, at $2.50	$40.00
Cleaning up old material.	
1 day, carpenter, at $2.50	$ 2.50
Painting.	
1 day foreman, at $2.50	$ 2.50
4 days, helper, at $1.75	7.00
Total labor	$ 9.50
Tools	4.18

Summary:

Materials.

	Total.	Pct.
7,255 ft. B. M. lumber, at $9.10	$ 65.95	33.1
5 M. shingles at $1.35	6.75	3.3
Millwork	28.96	14.6
Hardware	11.94	6.0
Paint	8.86	4.4
Masonry, 350 bricks, at $7.50	2.62	1.3
Total materials	$125.10	62.7
Labor.		
19 days building house, at $2.50	$ 47.50	23.7
Painting	9.50	4.7
Total labor	$ 57.00	28.4

		Per cent.
Total materials and labor	$182.10	91.1
Tools	4.18	2.0
Freight	13.79	6.9
Total	$200.07	100.0

	Per sq. ft.	Per cent.
Materials	$0.326	62.7
Labor	0.148	28.4
Tools	0.010	1.9
Freight	0.036	7.0
	$0.520	100.0

House No. 4.

Labor.

Building house:	
16.6 days, carpenter, at $2.50	$41.50
Building flue:	
1 day, carpenter, at $2.50	$2.50
1 day, helper, at $1.75	1.75
	$4.25
Painting.	
3 days, foreman, at $2.50	$ 7.50
2 days, helper, at $1.75	3.50
Total labor	$11.00
Tools	$ 3.82

Summary.

Materials.	Total.	Per cent.
7,255 ft. B. M. lumber, at $9.10	$ 65.95	33.6
5 M shingles, at $1.35	6.75	3.3
Millwork	28.96	14.7
Hardware	11.94	6.1
Paint	8.86	4.5
Masonry, 350 brick, $7.50	2.62	1.3
Total materials	$125.10	63.5
Labor.		
16.6 days building house, at $2.50	$ 41.50	21.1
Building flue	4.25	2.2
Painting	11.00	5.6
Total labor	$ 56.75	28.9
		Per cent.
Total materials and labor	$181.85	92.4
Tools	3.82	2.0
Freight	10.67	5.4
Total	$196.34	100.0
	Per sq. ft.	Per cent.
Material	$0.326	63.4
Labor	0.150	29.2
Tools	0.010	2.0
Freight	0.028	5.4
	$0.514	100.0

House No. 5.

Labor.

Unloading materials:	
1 day, carpenter, at $2.50	$ 2.50
Building house:	
20 days, carpenter, at $2.50	50.00
Building flue:	
3 days, carpenter, at $2.50	7.50
Painting:	
5 days, foreman, at $2.50	12.50
1 day, helper, at $1.75	1.75
Total labor	$14.25
Tools	$ 4.44

Summary.

Materials.	Total.	Per cent.
7,255 ft. B. M. lumber, at $9.10	$ 65.95	32.2
5 M shingles, at $1.35	6.75	3.2
Millwork	28.96	14.0
Hardware	11.94	5.8
Paint	8.86	4.3
Masonry, 350 bricks, $7.50	2.62	1.3
Total materials	$125.10	60.8

Labor.		
21 days building house, at $2.50	$ 52.50	25.4
Building flue	7.50	3.6
Painting	14.25	7.0
Total labor	$ 74.25	36.0
		Per cent.
Total materials and labor	$199.35	96.8
Tools	4.44	2.0
Freight	2.51	1.2
Total	$206.30	100.0
	Per sq. ft.	Per cent.
Materials	$0.326	60.6
Labor	0.193	36.0
Tools	0.012	2.1
Freight	0.007	1.3
	$0.538	100.0

It must be borne in mind that the cost of lumber is extremely low, even for the section in which this particular building work was done.

	Per sq. ft.	Per cent.
Materials	$0.326	60
Labor	0.160	30
Tools	0.010	2
Freight	0.045	8
	$0.541	100

Since the weight of the buildings is given in all cases, it is easy to calculate the freight for any given haul.

The average cost of the labor on these section houses was $62 per section house. There were 7,250 ft. B. M. in each section house, and, if we charge the full cost of the labor ($62) against this amount of lumber, we have a trifle less than $9 per 1,000 ft. B. M.

Cost of a Blacksmith Shop, Barn and Telegraph Office.*—We give in this issue the detailed cost of erecting a blacksmith shop, a telegraph office and a barn for railroad purposes in the Northwest. The work was done by day labor. It will be noticed that the price of lumber is very low:

BLACKSMITH SHOP.

Blacksmith shop, 20 x 30 ft.; area 600 sq. ft.

Weight:	Pounds.
2,120 ft. B. M., at 3,300 lbs.	6 996
4½ M shingles, at 150	675
Hardware	35
Total, 4 tons	7,706
Lumber:	
320 ft. B. M., at $8.00	$ 2.56
1,800 ft. B. M. second hand, at $4	7.20
2,120 ft. B. M. total, at $4.60 (av.)	$ 9.76
4½ M shingles, at $1.65	7.43

Engineering-Contracting, Nov. 6, 1907.

Hardware:

20 lbs. 8d. nails, at $2.10	$ 0.42
5 lbs. 20d. nails, at $2.00	.10
10 lbs. 3d nails, at $2.45	.25
Total hardware	$ 0.77

Labor:

Superintendence	$ 4.80
Carpenter, 10.4 days, at $2.10	21.82
Total labor	$26.62

SUMMARY.

Materials:	Totals.	Per cent.
2,120 ft. B. M., at $4.60	$ 9.76	21.4
4½ M shingles, at $1.65	7.43	16.7
Hardware	.77	1.9
Total materials	$17.96	40.0
Labor	$26.62	60.0
Grand total materials and labor	$44.58	100.0

	Cost sq. ft.	Per cent.
Materials	$0.030	40.0
Labor	0.044	60.0
Total	$0.074	100.0

The low cost of materials for this building is explained by the fact that six-sevenths of it was second-hand material. The building had no floor, and no studs were used in the sides. The cost per M ft. B. M. for the labor on the lumber was $12.55.

HAY BARN.

Hay barn, 20 x 35 ft.; area, 700 sq. ft.

Weight:	Pounds.
6,794 ft. B. M., 3,300 lbs.	22,420
7 M shingles, 150	1,050
Hardware, paint, etc.	475
Total, 12 tons	23,945

Lumber:

2,585 ft. B. M., at $7.50	$19.39
1,613 ft. B. M., at $8.00	12.90
496 ft. B. M., at $12.00	5.95
2,000 ft. B. M., at $8.00	16.00
100 ft. B. M., at $17.00	1.70
6,794 ft. B. M., total, at $8.23 (av.)	$55.91
7 M shingles, at $1.35	$ 9.45

Millwork:

2 window sash, at $0.75	1.50

Hardware:

200 lbs. 20d. nails, at $3.55	7.10
200 lbs. 10d. nails, at $3.55	7.10
20 lbs. 8d. nails, at $3.95	.79
3 lbs. 8d. nails	.15
3 lbs. 3d nails	.12
2 pair 10-in. strap hinges	.32
36 1½-in. screws	.07
1 8-in. hasp	.07
2 8-in. bar locks	.34
No. 10 screws	.01
Total hardware	$16.07

Paint:

5 gals. outside body paint, at $0.75	$ 3.75
2½ gals. oil, at $0.58	1.45
Total paint	$ 5.20

Labor:

Engineering	$ .80
Building hay barn:	
Foreman, 4 days, at $85 per month	10.95
Carpenter, 20 days, at $2.50	50.00
Carpenter, 6 days, at $2.25	13.50
Helpers, 5 days, at $1.75	7.00
Total	$81.45
Moving material from barn, helper, 1 day, at $1.75	$ 1.75
Cutting door in back and placing it, carpenter, 1 day, at $2.50	2.50
Painting barn:	
Carpenter, 1 day, at $2.50	2.50
Bridgeman, 2 days, at $2.25	4.50
Total	$ 7.00
Total labor	$93.50
Tools	$ 4.98

SUMMARY.

Materials:	Totals.	Per cent.
6,794 ft. B. M., at $8.23	$ 55.94	30.0
7 M shingles, at $1.35	9.45	5.1
Millwork	1.50	0.8
Hardware	16.07	8.6
Paint	5.20	2.7
Total materials	$ 88.16	47.2
Labor:		
Engineering	$ .80	0.5
Building	81.45	43.6
Moving lumber, etc.	1.75	0.9
Cutting door in back	2.50	1.3
Painting	7.00	3.7
Total labor	$ 93.50	50.0
Total materials and labor	$181.66	97.2
Tools	4.98	2.8
Grand total	$186.64	100.00

	Cost sq. ft.	Per cent.
Materials	$0.126	47.2
Labor	0.133	50.0
Tools	0.007	2.8
Total	$0.266	100.0

The cost of labor per M ft. B. M. of lumber used was $13.76.

TELEGRAPH OFFICE.

Telegraph office, 12 × 12 ft.; area, 144 sq. ft.

Weight:	Pounds.
2,332 ft. B. M., at 3,300 lbs.	7,695
2 M shingles, at 150 lbs.	300
Hardware, etc.	150
Total, 4 tons	8,145

Lumber:	
185 ft. B. M., at $12.00	$ 2.22
230 ft. B. M., at $15.00	3.45
340 ft. B. M., at $16.50	5.61
431 ft. B. M., at $15.00	6.47
243 ft. B. M., at $12.00	2.91
73 ft. B. M., at $26.00	2.03
200 ft. B. M., at $20.00	4.00
630 ft. B. M., at $30.00	18.90
2,332 ft. B. M. total, at $19.55 (av.)	$45.59
2 M shingles, at $3.50	$ 7.00
Millwork:	
8 window sashes	$ 3.28
Hardware:	
75 lbs. tar paper	$ 1.52
1 pair strap hinges	.20
Screws	.04
1 rim hook	.30
6 lbs. 6d. nails	.18
5 lbs. 8d. nails (finishing)	.31
10 lbs. 4d. nails	.30
30 lbs. 10d. nails	.84
Total hardware	$ 3.69
Labor:	
Foreman, 3 days, at $80 per month	$ 7.74
Carpenter, 11 days, at $2.50	27.50
Total labor	$35.24

SUMMARY.

Materials:	Totals.	Per cent.
2,332 ft. B. M., at $19.55	$45.59	48.0
2 M shingles, at $3.50	7.00	7.3
Millwork	3.28	3.5
Hardware	3.69	3.9
Total materials	$59.56	62.7
Labor	35.24	37.3
Grand total	$94.80	100.0

	Cost sq. ft.	Per cent.
Materials	$0.413	62.7
Labor	0.245	37.3
	$0.658	100.0

The cost per M ft. B. M. of lumber used for labor on the office was $15.11. This building had a floor in it and a ceiling, hence the cost per sq. ft. of area, and the cost per M ft. of lumber used would naturally be higher than in the other two buildings.

Cost of Forty Hand-Car Houses.*—In this article we give the cost in detail of erecting 40 frame hand-car houses on a division of a Western railroad. The price of lumber is given and other materials, as well as the labor costs. The work was done by "company men."

Forty hand-car houses built on one division; size, 8 x 12 ft.; area, 96 sq. ft.

Weight:	Pounds.
48,055 ft. B. M., at 3,300 lbs.	158,581
50 M shingles, at 150	7,500
Hardware and paint	2,400
Total, 84 tons	168,481

Timber:	
9,207 ft. B. M., at $11.50	$105.88
6,400 ft. B. M., at $11.50	73.60
1,200 ft. B. M. S. 1 S., at $13.75	16.50
4,053 ft. B. M. S. 1 S., at $28.75	116.52
3,407 ft. B. M., at $19.00	64.73
1,760 ft. B. M., at $19.00	33.44
2,333 ft. B. M. ceiling, at $32.50	75.82
2,725 ft. B. M. S. 1 S., at $14.00	38.15
2,270 ft. B. M. S. 1 S., at $28.75	65.26
8,500 ft. B. M. S. 1 S., at $28.75	244.33
6,200 ft. B. M., at $13.00	80.60
48,055 ft. B. M. total, at $19.03 (av.)	$914.83
50 M. shingles, at $1.25	62.50

Hardware:	
80 pairs 12-in. hinges, $1.21 per doz.	$ 8.06
80 5-in. hasp and staples	1.20
140 doz. 1¾-in. screws, at $0.23½ per gross	2.74
27 doz. ⅞-in. screws, at $0.08 per gross	.18
200 lbs. 3d nails, at $2.85	5.70
100 lbs. 6d nails, at $2.25	2.25
200 lbs. 16d nails, at $2.00	4.00
40 8-in. hinge hasps	1.25
40 padlocks	9.00
250 lbs. 20d nails, at $2.00	5.00
800 lbs. 10d nails, at $2.05	16.40
Total hardware	$ 55.78
100 gals. railroad paint, at $0.75	$ 75.00

Labor:	
Superintendent	$ 23.73
Foreman, 29 days, at $3.00	87.00
Carpenters, 121.5 days, at $2.50	303.75
Total labor	$414.48
Tools	$ 3.75

*Engineering-Contracting, Nov. 20, 1907.

For one hand-car house, weighing 2.1 tons, we give the following summary:

Materials:	Total.	Per cent.
1,201 ft. B. M., at $19.03	$22.87	60.0
1¼ M shingles, at $1.25	1.56	4.1
Hardware	1.39	3.7
Paint	1.87	4.9
Total materials	$27.69	72.7
Labor	$10.36	27.1
Total materials and labor	$38.05	99.8
Tools	$ 0.09	0.2
Grand total	$38.14	100.0

	Cost per sq. ft.	Per cent.
Materials	$0.288	72.7
Labor	0.108	27.1
Tools	0.001	0.2
Total	$0.397	100.0

The cost per M ft. B. M. for the entire labor on these buildings was $8.62, which was quite low.

Cost of Six Tool Houses.*—In this article we give the cost in detail of building six frame tool houses for use on railroads. The labor was performed by company forces. The costs are summarized so as to allow of comparison with other cheap structures, like those that have appeared in our previous issues in this series of articles. Lists of materials and prices are given as well as wages. The cost of lumber was very low.

EXAMPLE I.

Tool house, 8 x 12 ft.; area, 96 sq. ft.

Weight:	Pounds.
1,000 ft. B. M., at 3,300 lbs.	3,300
1¼ M shingles, at 150	188
Hardware	50
Total, 1¾ tons	3,538

Lumber:	
323 ft. B. M., at $9	$ 2.91
630 ft. B. M., at $11	6.93
48 ft. B. M. flooring, at $20	.96
1,001 ft. B. M. total, at $10.80 (av.)	$10.80
1¼ M shingles, at $1.80	$ 2.25
Hardware:	
Bolts	$ .82
3 lbs. 3d nails, $2.76	.08
10 lbs. 8d nails, $2.35	.24
5 lbs. 20d nails, $2.25	.11
1 gal. paint	.60
2 pr. 8-in. tie hinges, 4 ct.	.08
1 8-in. hinge hasp, 5 ct.	.05
½ gross 1-in. No. 10 screws, 14 ct.	.07
1 Yale padlock	.43
Total	$ 2.48

*Engineering-Contracting, Oct. 30, 1907.

Labor:

Engineering	$ 1.65
Building house, 4.5 days, carpenter, $2.50	11.25
Total	$12.90

This includes painting.

Tools	$ .48

SUMMARY.

Materials:	Totals.	Per cent.
1,001 ft. B. M., at $10.80	$10.80	38.0
Shingles	2.25	7.4
Hardware	2.48	8.5
Total materials	$15.53	53.9
Labor:		
Engineering	$ 1.65	5.7
Carpenter	11.25	38.9
Total labor	$12.90	44.6
Total materials and labor	$28.43	98.5
Tools	.48	1.5
Freight	.00	0.0
Grand total	$28.91	100.0

	Cost per sq. ft.	Per cent.
Materials	$ .161	53.9
Labor	.134	44.6
Tools	.005	1.5
Total	$ .300	100.0

It will be noted that the carpenter labor, as above given, cost $11.25 per 1,000 ft. B. M. in the tool house.

EXAMPLE II.

Tool house, 12 x 14 ft., and oil house, 10 x 32; area, 168 sq. ft. and 320 sq. ft. Total area, 488 sq. ft.

Weight:	Pounds.
Lumber and millwork	13,700
5½ M shingles, at 150	825
Hardware and paint	200
Total, 7⅓ tons	14,725

Lumber:	
416 ft. B. M., at $9	$ 3.74
700 ft. B. M., at $12	8.40
1,360 ft. B. M., at $8.50	11.56
1,100 ft. B. M., at $12	13.20
450 ft. B. M., at $9	4.05
4,026 total, at $10.17 (av.)	$40.95

Millwork:	
Battens	$ 1.92
1 door frame and door	2.95
2 window frames and sash	5.90
Total	$10.77
5½ M shingles, at $1.45	$ 7.98

Hardware:

100 lbs. 8d nails	$ 2.56
20 lbs. 30d nails, at $2.46	.49
1 hasp	.05
2 hinges and hasps	.10
1 pair butts	.04
20 lbs. 6d nails, at $2.66	.53
1 galv. iron chimney	1.04
	$ 4.81

Paint:

6 gals. outside body paint, 75 cts.	$ 4.50
1 gal. outside trim paint	.70
½ gal. turpentine	.22
¼ gal. Japan dryer	.20
	$ 5.62

Labor:

Building tool and oil house:	
Carpenters, 20 days, at $2.50	$50.00
Putting up shelving:	
Carpenter, 4 days, at $2.50	10.00
Painting, helper, 1 day, at $1.75	1.75
Total labor	$61.75
Tools	$ 2.34

SUMMARY.

Materials:	Totals.	Per cent.
4,026 ft. B. M., at $10.17	$ 40.95	30.5
Millwork	10.77	8.0
Shingles	7.98	5.9
Hardware	4.81	3.5
Paint	5.62	4.1
Total material	$ 70.13	52.0
Labor:		
Building	$ 60.00	44.7
Painting	1.75	1.3
Total labor	$ 61.75	46.0
Total material and labor	$131.88	98.0
Tools	2.34	2.0
Freight	.00	0.0
Grand total	$134.22	100.0

	Cost per sq. ft.	Per cent.
Materials	$0.144	52.0
Labor	0.126	46.0
Tools	0.005	2.0
Total	$0.275	100.0

It will be noted that the labor cost about $15 per M.

It is noteworthy in this instance to record that the foreman carpenter on this job was discharged for inefficiency, owing to the high cost of building these two sheds. One of these buildings had windows in it and shelving, which should have made the labor costs higher than in Example I, where neither windows nor shelves were used. A comparison shows that the cost per square foot of area in Example II was lower than in all the cases given except Example V. The cost was 2½ cts. lower than Example I, 1 ct. of which was

in the reduced cost of labor. This makes evident the fact that cost data and their analysis form the only true way of telling of the efficiency of workmen and methods, provided the records are kept honestly and intelligently.

EXAMPLE III.

Tool house, 8 x 12 ft.; area, 96 sq. ft.

Weight:	Pounds.
1,110 ft. B. M. lumber, at 3,300	3,663
1 1/5 M shingles, at 150	180
Hardware and paint	50
Total, 2 tons	3,893

Lumber:	
758 ft. B. M., at $10.50	$ 7.95
352 ft. B. M., at $7.50	2.64
1,110 ft. B. M. total, at $9.54 (av.)	$10.59
1,200 shingles, at $1.90	$ 2.28
Hardware:	
3-in. bolts	$ 1.60
5 lbs. 20d nails, at $2	.10
5 lbs. 8d nails, at $2.10	.11
10 lbs. 10d nails, at $2.05	.20
Total	$ 2.01
Paint:	
2 gals. outside body paint, at 60 cts.	$ 1.20
Labor:	
Loading material for tool house:	
Carpenter, 1 day, at $2.50	$ 2.50
Erecting tool house:	
Carpenter, 2 days, at $2.50	5.00
Helper, 6 days, at $2	12.00
Total	$19.00
This includes painting.	
Tools	$ 1.57

SUMMARY.

Materials:	Totals.	Per cent.
1,110 ft. B. M., at $9.54	$10.59	28.8
1,200 shingles, at $1.90	2.28	6.2
Hardware	2.01	5.5
Paint	1.20	3.3
Total material	$16.08	43.8
Labor	$19.00	51.9
Total materials and labor	$35.08	95.7
Tools	1.57	4.3
Freight	0.00	0.0
Grand total	$36.65	100.0

	Cost per sq. ft.	Per cent.
Materials	$0.167	43.8
Labor	0.198	51.9
Tools	0.016	4.3
Total	$0.381	100.0

It will be noted that the labor cost nearly $17.50 per M, which is excessive.

EXAMPLE IV.

Tool house, 8 x 12 ft.; area, 96 sq. ft.

Weight:	Pounds.
1,247 ft. B. M., at 3,300 lbs.	4,115
1¼ M shingles, at 150	187
Hardware and paint	65
Total, 2 tons	4,367

Lumber:	
577 ft. B. M., at $7	$ 4.04
180 ft. B. M., at $7	1.26
490 ft. B. M., at $8	3.92
1,247 ft. B. M. total at $7.40 (av.)	$ 9.22
1¼ M shingles, at $1.50	$ 1.87
Hardware:	
10 lbs. 20d nails, at $2.46	$ .25
20 lbs. 8d nails, at $2.56	.51
5 lbs. 3d nails, at $2.91	.15
2 prs. hinges	.12
1 hasp	.05
1 padlock	.16
Total	$ 1.24
Paint:	
4½ gals. outside body paint, at 75 cts.	$ 3.38
½ gal. boiled oil, at 70 cts.	.35
Total	$ 3.73
Labor:	
Carpenter, 3 days, at $2.50	$ 7.50
Carpenter, 1 day, at $2.25	2.25
Helper, 1 day, at $1.75	1.75
Painting, helper, 1 day, at $1.75	1.75
Total	$13.25
Tools	.95

SUMMARY.

Materials:	Totals.	Per cent.
1,247 ft. B. M., at $7.40	$ 9.22	30.4
1¼ M shingles, at $1.50	1.87	6.1
Hardware	1.24	4.1
Paint	3.73	12.3
Total materials	$16.06	52.9
Labor:		
Building	$11.50	38.0
Painting	1.75	5.7
Total labor	$13.25	43.7
Total material and labor	$29.31	96.6
Tools	.95	3.4
Freight	.00	0.0
Grand total	$30.26	100.00

	Cost per sq. ft.	Per cent.
Materials	$0.167	52.9
Labor	0.138	43.7
Tools	0.001	3.4
Total	$0.306	100.0

It will be noted that the labor cost $10.50 per M.

Example V.

Double tool house, 12 x 30 ft.; area, 360 sq. ft.

Weight:	Pounds.
3,606 ft. B. M., at 3,300 lbs.	11,365
3½ M shingles, at 150 lbs.	525
Hardware	75
Total, 6 tons	11,965

Lumber:

1,019 ft. B. M., at $8	$ 8.15
708 ft. B. M., S. 1 S., at $8.50	6.02
879 ft. B. M., at $8	7.03
288 ft. B. M., at $8.50	2.45
232 ft. B. M., at $8	1.86
318 ft. B. M., at $4	1.27
3,444 ft. B. M. total, at $7.77 (av.)	$26.78
3½ M shingles, at $1.40	$ 4.90

Hardware:

20 lbs. 4d nails, at $3.80	$ .76
6 lbs. 20d nails, at $3.50	.21
8 lbs. 8d nails, at $3.60	.29
24 lbs. 10d nails, at $3.55	.85
6 lbs. 30d nails, at $3.50	.21
4 pairs hinges	.48
2 pairs hasps	.14
2 Yale padlocks	.88
Total	$ 3.82

Labor:

Carpenter, 12.1 days, at $2.50	$30.25
Tools	2.21
Freight	.76

Summary.

Materials:	Totals.	Per cent.
3,444 ft. B. M., at $7.77	$26.78	39.0
Shingles 3½ M, at $1.40	4.90	7.2
Hardware	3.82	5.6
Total materials	$35.50	51.7
Labor	$30.25	43.8
Total materials and labor	$65.75	95.5
Tools	2.21	3.3
Freight	.76	1.2
Grand total	$68.72	100.0

	Cost per sq. ft.	Per cent.
Materials	$0.098	51.7
Labor	0.084	43.8
Tools	0.007	3.3
Freight	0.002	1.2
Total	$0.191	100.0

It will be noted that the labor cost $8.60 per M.

Example VI.

Tool house, 8 x 12 ft.; area, 96 ft.

Weight:	Pounds.
1,247 ft. B. M., at 3,300 lbs.	4,115
1¼ M shingles, at 150	187
Hardware	60
Total, 2 tons	4,362
Lumber:	
577 ft. B. M., at $7	$ 4.04
180 ft. B. M., at $7	1.26
490 ft. B. M., at $8	3.92
1,247 ft. B. M. total at $7.39 (av.)	$ 9.22
1¼ M shingles, at $1.50	$ 1.87
Hardware:	
Bolts	$ .42
10 lbs. 20d nails, at $2.46	.25
20 lbs. 8d nails, at $2.56	.51
5 lbs. 3d nails, at $2.91	.15
2 pairs hinges	.12
1 hasp	.05
1 padlock	.16
Total	$ 1.66
Paint:	
2½ gals. outside body paint, at 75 cts.	$ 1.88
½ gal. oil, at 70 cts.	.35
	$ 2.23
Labor:	
Carpenter, 6.3 days, at $2.50	$15.75
Carpenter, 1 day, at $2.25	2.25
Helper, 2.5 days, at $1.75	4.37
Total	$22.37
Tools	.92

Summary.

Materials:	Totals.	Per cent.
1,247 ft. B. M., at $7.39	$ 9.22	24.0
1¼ M shingles, at $1.50	1.87	4.9
Hardware	1.66	4.3
Paint	2.23	5.9
Total materials	$14.98	39.1
Labor	22.37	58.4
Total materials and labor	$37.35	97.5
Tools	.92	2.5
Freight	.00	0.0
Grand total	$38.27	100.0

	Cost per sq. ft.	Per cent.
Materials	$0.156	39.1
Labor	0.233	58.4
Tools	0.001	2.5
Total	$0.390	100.0

It will be noted that the labor cost $18 per M, which is excessive.

A number of these tool houses were 8 x 12, giving 96 sq. ft. of area in the building and needing for their construction a little more than a thousand feet of lumber. Their cost ran from $28 to $38 . A comparison of these buildings with the cost of building a large number of shacks for camps in building railroads in the South will be of interest. These camps were built by one of the editors of this journal.

They were about 10 x 10, and had a slanting roof. A door made from boards was used in it, and a sliding board window was put in one side. A bunk was also built in it, but there was no floor. A thousand feet of lumber was used in building the shack. The roof was covered with tar paper, and strap hinges, hasp and padlock were used on the door. The lumber on a large number built in Tennessee cost $10 per M; the tar paper, nails and hardware cost $2, making a cost of materials of $12. Carpenters were paid $3.50 per day, and 3 carpenters completed a building in a day, making a cost of about $10 for labor, or a total cost of $22 per shack.

A comparison with the tool houses shows that if paint and shingles had been used these shacks would have cost a few dollars more for materials and slightly raised the cost of labor; but wages paid by the contractor on the shacks were $1 per day higher, which about offsets the increased cost of materials.

We have pointed out before that a contractor who pays $3.50 a day for carpenters will usually get more work for the money than will a railroad company that pays $2.50 to its carpenters. A comparison of the cost of labor per square foot as listed above with 10 cts. per square foot as paid for these shacks shows plainly that this is true.

Capacity and Cost of Ice Houses.—The nominal capacity of an ice house is generally stated in tons of ice, and is generally taken to mean the capacity up to the eaves. By stacking the ice up higher under the roof, working from doors in the roof or gable ends, the capacity can be increased 10% or more. About 34 cu. ft. of ice make a ton of 2,000 lbs., the ice weighing 58.7 lbs. per cu. ft. It is not unusual to assume a weight of 60 lbs. per cu. ft. for convenience of calculation. Allowing for voids between the cakes of ice it is customary to allow 36 cu. ft. per ton, but this is usually too low, a fair average being nearer 40 cu. ft. per ton of 2,000 lbs. In a large, well-built ice house, only 10% of the ice is lost annually by melting and evaporation, but in smaller houses the loss is larger.

The following are dimensions and nominal capacities of some standard ice houses on the Lehigh Valley R. R.:

Size.	Capacity cu. ft.	Capacity tons.
18 × 32 ft. × 12 ft. height of frame....	6,912	150
32 × 86 ft. × 28 ft. height of frame....		1,500
30 × 120 ft. × 24 ft. height of frame....	86,400	2,000

If frame ice houses cost 5 cts. per cu. ft. to build, the equivalent cost is $2.00 per ton of ice capacity.

Cost of Six Ice Houses.*—The work was done by railway company forces. It will be noted that the price of lumber was very low.

EXAMPLE I.

Ice House 30 × 48 ft.

Weight.	Pounds.
26,000 ft. B. M. at 3,300 lbs. equals	85,800
17¼ M. shingles at 150 lbs.	2,600
Hardware, etc.	2,000
Total, 45 tons	90,400

Lumber:	
1,280 ft. B. M. at $8	$ 10.24
7,333 ft. B. M. at $8	58.66
2,432 ft. B. M. at $8.50	20.67
2,053 ft. B. M. at $7.50	15.40
4,360 ft. B. M., 1 in., at $11	47.96
777 ft. B. M., 1 in., at $12	9.32
4,420 ft. B. M. drop siding at $13.50	59.67
400 ft. B. M. flooring at $18.50	7.40
3,072 ft. B. M. S. H., 8 × 16-in., at $4	12.28
26,127 ft. B. M. total at $9.20 (av.)	$241.54
17¼ M. shingles at $1.75	$30.19
Hardware:	
390 lbs. rods and bolts at $2.55 per 100 lbs.	$ 9.95
1,300 lbs. at $2 per 100 lbs.	26.00
Bolts, nuts and washers	11.75
6 padlocks at 13 cts.	.78
Total hardware	$48.48
Paint:	
27 gals. paint at 50 cts.	$13.50
3 gals. oil at 37.5 cts.	1.12
Total paint	$14.62
Labor:	
Engineering	$20.80
Loading material:	
1.6 days carpenter at $2.50	$ 4.00
3.2 days laborer at $2	6.40
4.8 total	$10.40
Unloading material:	
1 day carpenter	$ 2.50

*Engineering-Contracting, Oct. 9, 1907.

Building ice house:

18.5 days foreman at $80 per mo	$ 47.74
102.1 days carpenter at $2.50	256.75
43.1 days helper at $2	86.20
163.7 days total at $2.37	$390.69

Painting ice house:

7 days helper at $2	$14.00
Tools	32.50

SUMMARY.

Materials:	Totals.	Per cent.
26,127 ft. B. M. at $9.20	$241.54	28.4
Shingles	30.19	3.5
Hardware	48.48	5.5
Paint	14.62	1.7
Total material	$334.83	39.1
Labor:		
Engineering	$ 20.80	2.5
4.8 days loading	10.40	1.2
1 day unloading	2.50	.3
163.7 days building at $2.37	390.69	46.0
7 days painting at $2	14.00	1.4
Total labor	$439.39	51.7
Total materials and labor	$774.22	90.8
Tools	32.50	3.8
Freight	45.00	5.4
Grand total	$851.72	100.00

	Cost per sq. ft.	Per cent.
Materials	$0.232	39.1
Labor	.305	51.7
Tools	.022	3.8
Freight	.031	5.4
Total	$0.590	100.0

EXAMPLE II.

Ice House 30 × 60.

Weight:	Pounds.
18,600 ft. B. M. at 3,300 lbs. equals	61,380
Hardware	700
Total, 31 tons	62,080

Lumber:

10,196 ft. B. M. at $6.50	$ 66.27
5,414 ft. B. M. at $7	37.90
1,520 ft. B. M. at $7.50	11.40
192 ft. B. M. s1s, at $9	1.73
320 ft. B. M., s4s, at $9.50	3.04
300 ft. B. M., ceiling, at $10.50	3.15
675 ft. B. M., 1 × 3 battens, at $16	10.80
18,617 ft. B. M. total at $7.22 (av)	$134.29
19 M. shingles, Star A, at $1.15	$ 21.85

Hardware:

680 lbs. nails at .016 ct.	$ 10.04

Paint:

10 gals. outside paint at 70 cts.	$ 7.00

Labor:

Unloading lumber:

1 day carpenter at $2.50	$ 2.50
3 days laborers at $1.60	4.80
4 days total at $1.82	$ 7.30

Erecting ice house:

93.5 days carpenter at $2.50	$233.75
12.5 days helper at $1.75	21.85
106 days total at $2.40	$255.60

Painting:

4 days foreman at $75 per month	$ 9.67
2 days painter at $2.50	5.00
6 days total at $2.45	$ 14.67
Tools	19.00

SUMMARY.

Materials:	Totals.	Per cent.
18,617 ft. B. M. at $7.22	$134.29	25.1
19 M. shingles at $1.15	21.85	4.1
690 lbs. nails at 1.6 cts	10.04	1.8
10 gals. paint at 70 cts	7.00	1.5
Total	$173.18	32.5
Labor:		
4 days unloading lumber at $1.82	$ 7.30	1.3
106 days erecting at $2.40	255.60	47.5
6 days painting at $2.45	14.67	2.6
Tools	19.00	3.5
Total materials and labor	$470.75	87.4
31 tons freight, actual (excessive)	67.70	12.6
Total	$538.45	100.0

	Cost per sq. ft.	Per cent.
Materials	$0.096	32.5
Labor	0.164	54.9
Freight	0.037	12.6
Total	$0.297	100.0

EXAMPLE No. III.

Ice House 24 × 48.

Weight:	Pounds.
16,665 ft. B. M. at 3,300 lbs	54,994
15½ M. shingles at 150 lbs	2,325
Hardware	1,500
Total (29 tons)	58,819

Lumber:

624 ft. B. M. S. H. at $7	$ 4.37
6,420 ft. B. M. at $11.50	73.83
240 ft. B. M. at $12.50	3.00
112 ft. B. M., s2s1E, at $13.40	1.50
328 ft. B. M., at $17.50	5.74
5,441 ft. B. M., s1s, No. 1, at $17.25	93.86
3,500 ft. B. M., ship lap, No. 2, at $21	73.50
16,665 ft. B. M. total (av.), $15.35	$255.80
15½ M. shingles at $2	$ 31.00

Hardware:

125 lbs. 20d wire nails at $1.60	$ 2.00
355 lbs. 10d wire nails at $1.75	6.21
70 lbs. 4d wire nails at $2.10	1.47
Bolts, plates, nuts and washers	10.19
Padlocks and hinges	1.78
Total hardware	$ 21.65

Paint:

10 gals. outside at 84 cts	$ 8.40
9 gals. oil at 55 cts	4.95
Total paint	$ 13.35

Labor:

Building:

10 days carpenter at $2.64	$ 26.40
41 days carpenter at $2.25	92.25
6 3-10 days foreman at $2.50	15.75
	$134.40

Painting:

6 days painter at $2	$ 12.00
Foreman	1.56
Total	$ 13.56

SUMMARY.

Materials:		Per cent.
16,665 ft. B. M. at $15.35	$255.80	50.9
Shingles	31.00	6.2
Hardware	21.65	4.3
Paint	13.35	2.6
Total materials	$321.80	63.9
Labor:		
Building	$134.40	26.9
Painting	13.56	2.9
Total labor	$147.96	29.8
Total materials and labor	$469.76	93.7
Tools	2.94	.5
Total	$472.70	94.2
Freight	29.00	5.8
Grand total	$501.70	100.0

	Cost per sq. ft.	Per cent.
Materials	$0.280	64.0
Labor	0.130	29.8
Tools	0.005	.5
Freight	0.015	5.7
Total	$0.430	100.0

EXAMPLE IV.

Ice House 24 × 48.

Weight:	Pounds.
16,694 ft. B. M. at 3,300 lbs.	55,090
15 M. shingles at 150 lbs.	2,250
Hardware	1,000
Total (29 tons)	58,340

Lumber:	
3,200 ft. B. M. at $18	$ 57.60
256 ft. B. M. at $9	2.30
960 ft. B. M. at $9.50	9.12
4,500 ft. B. M., sls, at $17.50	78.75
108 ft. B. M., sls, at $17.25	1.86
221 ft. B. M., at $13	2.87
2,498 ft. B. M., at $10	27.24
312 ft. B. M., flooring, at $27.50	8.58
719 ft. B. M. at $6.50	4.67
3,120 ft. B. M. at $11	34.32
16,694 ft. B. M., total average, $13.35	$227.31
15 M. shingles at $2	$ 30.00
Hardware:	
Rods, washers, etc.	$ 12.67
200 lbs. 20d nails	3.20
60 lbs. 4d nails	1.29
400 lbs. 10d nails	7.00
Locks, hinges, etc.	2.08
Total hardware	$ 26.24
Paint:	
12.5 gals. paint at 90 cts.	$ 11.35
5.5 gals. oil at 59 cts.	3.25
Total paint	$ 14.60
Labor:	
Building house:	
Supervision	$ 31.19
11.5 days foreman at $85 per month	34.91
45.5 days carpenter at $2.48	112.73
Total	$178.83
Banking cinders around house:	
1 day foreman at $1.74	$1.74
6 days laborers at $1	6.00
Total	$7.74
Painting:	
2 days painter at $2.25	$4.50
3 days painter at $1.75	5.25
Total	$9.75

SUMMARY.

Material:		Per cent.
16,694 ft. B. M. at $13.35	$227.31	43.3
15 M. shingles at $2	30.00	5.7
Hardware	26.24	5.0
Paint	14.60	2.8
	$298.15	56.8
Labor:		
Building house	$178.83	34.1
Banking cinders	7.74	1.5
Painting	9.75	1.8
	$196.32	37.4
Materials and labor	$494.47	94.2
Tools	.77	0.1
Total	$495.24	94.3
Freight	29.00	5.7
Grand total	$524.24	100.0

	Cost per sq. ft.	Per cent.
Materials	$0.259	56.8
Labor	0.170	37.4
Tools	0.001	0.1
Freight	0.025	5.7
Total	$0.455	100.0

EXAMPLE V.

Ice House 24 × 48.

Weight:	Pounds.
18,247 ft. B. M. at 3,300 lbs	60,325
14 M. shingles at 150 lbs	2,100
Hardware	1,000
Total (32 tons)	63,425

Lumber:	
576 ft. B. M. at $12.50	$ 7.20
4,560 ft. B. M. at $11.50	52.44
3,500 ft. B. M., not ship lap, at $27.50	96.25
224 ft. B. M., No. 2 flooring, at $13.50	3.02
4,500 ft. B. M., No. 2 s1s, at $13.75	61.88
662 ft. B. M. at $11.50	7.61
225 ft. B. M. at $13	2.93
18,247 ft. B. M. total (av) $12.68	$231.33
14 M. shingles at $2.75	$ 38.50

Hardware:	
2 kegs 20d nails at $2	$ 4.00
2 kegs 10d nails at $2.05	4.10
80 lbs. 4d nails at $2.45	1.96
Locks, hinges, etc.	1.08
Total hardware	$ 11.14

Labor:

21 days foreman at $3	$ 63.00
25 days carpenter at $2.75	67.25
12.5 days carpenter at $2.50	31.25
1 day foreman at $2.14	2.14
19 days laborer at $1.50	28.50
Total	$192.14

SUMMARY.

Materials:		Per cent.
Lumber, 18,247 ft. B. M. at $12.68	$231.33	45.8
Shingles, 14 M. at $2.75	38.50	7.6
Hardware	11.14	2.2
	$280.97	55.6
Labor	$192.14	38.1
Freight	32.00	6.3
	$505.11	100.0

	Cost per sq. ft.	Per cent.
Materials	$0.243	55.6
Labor	0.167	38.1
Freight	0.028	6.3
Total	$0.438	100.0

EXAMPLE VI.

Ice House 24 × 48

		Per cent.
Materials	$322.81	62.2
Labor	164.72	31.8
Tools	1.69	0.3
Freight	29.00	5.7
	$518.22	100.0

	Cost per sq. ft.	Per cent.
Materials	$0.280	62.2
Labor	0.143	31.8
Tools	0.001	0.3
Freight	0.025	5.7
Total	$0.449	100.0

The labor cost per thousand feet of lumber in place was as follows:

	Per M.
Example No. I	$16.00
Example No. II	15.60
Example No. III	8.70
Example No. IV	11.00
Example No. V	10.70
Example No. VI	10.00
Average	$12.00

Cost of 11 Ice Houses.—The following costs relate to work done by railway company labor in the Pacific Northwest, carpenters receiving $2.50 per 10-hr. day.

A 200-ton ice house, 22 x 31 ft., contained 18 M. The average cost of five of these houses was:

	Totals.	Per sq. ft.
Materials	$270	$0.40
Labor	177	0.26
Total	$447	$0.76

Since there were 18 M. in each house, the labor cost was $10 per M.

A 1,000-ton ice house, 30 x 86 ft., contained 54 M. The average cost of six of these houses was:

	Total.	Per sq. ft.
Materials	$ 670	$0.26
Labor	500	0.20
Total	$1,170	$0.46

The labor cost was a little more than $9 per M.

Cost of Car Shops.—Car shops were built in six months (1906) by contract for the Wabash Ry., at Decatur, Ill.

The total cost of the plant was $368,000, including buildings, machinery, shop yard, grading and track.

The cost of the different buildings was as follows:

	Per cu. ft. cts.
Car shop, 88 × 464 ft.	2.7
Blacksmith and machine shop, 80 × 294	3.0
Storehouse and 2-story office bldg at one end, 40 × 464	5.5
Wood mill, 80 × 238	2.9
Cabinet, upholstering, etc., shop 40 × 350	4.5
Power house, 60 × 108, brick	3.4
Lavatory building	5.4
Dry kiln, reinforced concrete roof, floor, etc	11.1
Dry lumber sheds	2.3
Iron, coal and coke sheds	3.5
Material sheds and racks	5.8

All the large shop buildings have timber frames with hollow walls formed of plaster (1 to 1½ ins. thick), on expanded metal lath (24 gage), secured to 1½-in. round rods stapled to the timbers. The shop buildings have maximum window area.

Cost of Engine Roundhouses.—Mr. R. D. Coombs gives the following bills of materials and estimated costs of wooden, of steel framed, and of reinforced concrete roundhouses. Each stall is 73 ft. long, 24 ft. wide at one end and 14 ft. wide at the other, giving an average width of 19 ft., or an area of 912 sq. ft.

The estimated cost of one stall of the wooden roundhouse with brick walls is:

Wooden Roundhouse.

Roof and Center Columns:

380 ft. B. M. spruce monitor sheathing at $35.00...	$ 13.30
320 ft. B. M. pine monitor purlins at $40.00........	12.80
345 ft. B. M. cypress monitor framing at $60.00...	20.70
1,512 ft. B. M. spruce roof sheathing at $35.00......	52.92
2,238 ft. B. M. pine roof purlins at $40.00............	89.52
675 ft. B. M. pine girders at $40.00...............	27.00
601 ft. B. M. pine columns and caps at $40.00.....	24.04
65 ft. B. M. spruce bridging, etc. at $40.00.......	2.60
6,136 ft. B. M. total timber........................	$242.88
70 lbs bolts at $0.03..................................	2.10
8 pivot windows, incl. painting, at $4.00..........	32.00
2 fixed windows, incl. painting, at $2.50...........	5.00
2.92 cu. yds. concrete column foundation at $6.00..	17.52
1,513 sq. ft. tarred felt roofing at $0.04............	60.52
Smoke-jack	30.00
4,200 sq. ft. painting at $0.0225....................	94.50
700 lbs. cast iron column base at $0.0275..........	19.25
Total for roof and center columns..............	$503.77

Walls:

12.5 cu. yds. brick wall at $6.50..................	$ 81.25
1.8 cu. yds. brick arch at $8.00.....................	14.40
3,200 lbs. cast iron column at $0.0275..............	88.00
7.2 cu. yds. concrete wall foundation at $6.00.......	43.20
1.46 cu. yds. concrete post foundation at $6.00......	8.76
2 lifting windows, incl. painting, at $10.00..........	20.00
200 ft. B. M. cypress window framing at $60.00....	12.00
1 double door, incl. painting......................	50.00
Total for walls......................................	$317.61
Grand total for one stall........................	$822.38

The cost of each stall of a steel framed roundhouse with brick walls is estimated as follows:

Steel Framed Roundhouse.

Roof and Center Columns:

380 ft. B. M. spruce monitor sheathing at $35.00...	$ 13.30
320 ft. B. M. pine monitor purlins at $40.00.........	12.80
345 ft. B. M. cypress monitor framing at $60.00....	20.70
2,330 ft. B. M. spruce roof sheathing at $35.00......	81.55
135 ft. B. M. spruce nailing strips at $40.00.......	5.40
1,550 lbs. steel columns at $0.03...................	46.50
7,650 lbs. steel purlins at $0.03....................	228.00
1,900 lbs. steel girders at $0.03.....................	57.00
450 lbs. steel knees, etc. at $0.03................	13.50
100 lbs. bolts and fillers at $0.03.................	3.00
8 pivot windows, incl. painting, at $4.00........	32.00
2 fixed windows, incl. painting, at $2.50........	5.00
2.26 cu. yds. concrete column found. at $6.00......	13.56
0.14 cu. yds. column found. cap at $10.00..........	1.40
1,470 sq. ft. roofing at $0.04......................	58.80
Smoke jack	30.00
1,250 sq. ft. painting, steel at $0.01................	12.50
1,900 sq. ft. painting, wood at $0.0225.............	42.75
Total for roof and center columns...............	$677.76
Brick walls (same as for wood roundhouse)......	317.61
Grand total	$995.37

The cost of one stall of reinforced concrete roundhouse is estimated thus:

REINFORCED CONCRETE ROUNDHOUSE.

Roof and Center Columns:	
3,770 lbs. reinforcing rods at $0.03	$113.10
42.56 cu. yds. concrete superstructure at $15.00	638.88
2.3 cu. yds. concrete col. bases at $6.00	13.80
410 ft. B. M. pine, monitor purlins at $40.00	16.40
420 ft. B. M. spruce, monitor sheathing at $35.00	14.70
280 ft. B. M. cypress monitor frame at $60.00	16.80
8 pivot windows at $4.00	32.00
2 fixed windows at $2.50	5.00
1,440 sq. ft. roofing at $0.04	57.60
38 ft. gutter at $0.16	6.08
18 ft. down spout at $0.30	5.40
Smoke jack	30.00
700 sq. ft. painting at $0.0225	15.75
Total for roof and center columns	$965.51
Walls:	
640 lbs. reinforcing rods at $0.03	$ 19.20
350 lbs. channels at $0.03	10.50
2,330 lbs. cast iron column at $0.0275	64.07
215 sq. ft. expanded metal No. 10 at $0.027	5.80
6.42 cu. yds. reinforced concrete walls at $15.00	96.30
7.09 cu. yds. concrete foundations at $6.00	42.54
0.74 cu. yds. concrete door post at $6.00	4.44
4 lifting windows at $10.00	40.00
Double door	40.00
Total for walls	$346.85
Total for one stall	$1,312.36

Cost of Roundhouse, Coaling Station, Turntable, Etc.*—Mr. A. O. Cunningham gives data of which the following is a brief abstract. See *Engineering-Contracting* for full description of the plant with drawings.

In 1907, the Wabash R. R. built a new engine terminal plant at Decatur, Ill., where 100 engines are cared for daily.

The roundhouse has a wooden frame resting on concrete foundations. The walls are of wooden girts to which expanded metal is fastened on both sides. The expanded metal on the outer surface is plastered on both sides with a mixture of Portland cement, lime and sand, and cocoanut fiber. The expanded metal on the inner surface is, of course, only coated on one side with the same kind of plaster. This construction provides a wall with a hollow space of air between, so that dampness cannot penetrate to the inner surface. The air space forms a good insulator to keep the building warm in winter and cool in summer. The plaster applied to these walls consists of 1 bbl. of lime mixed with 15 bbls. of sand and 4 lbs. of cocoanut fiber, the whole being mixed thoroughly with water and allowed to stand for at least two weeks so as to give the lime time enough to slack thoroughly. One part of Portland cement is added to three parts of this mixture, with enough water added to make a plastic

**Engineering-Contracting*, Apr. 28, 1909.

mortar. This is applied to the expanded metal and allowed to harden. This is called a scratch coat. On this coat is plastered another layer of mortar, composed of 3 parts of sand to 1 part of cement. The plaster on the expanded metal on the outer surface of the house is 1½ ins. thick, and that on the inner surface about ¾ in. thick. This hollow wall extends completely around the outside of the house, and from the ground to a height of 5 ft. The exterior face of the wall is painted with a waterproofing compound. On this wall is placed a continuous line of windows, which extend to the underside of the eaves of the building, thus providing plenty of light, which is very essential in such buildings. The cost of a wall of this description is slightly less than brick, but a saving is made because brickwork requires foundations to support it, while this construction requires only those necessary to support the posts. Also lintels are required over openings in brickwork, and none are required in this kind of a wall. A further advantage in this construction is that a continuous line of windows may be used, while with brickwork this is not possible, on account of the pilasters. The windows are made so that the two lower sashes are hung together with copper chains over pulleys; thus when one is raised the other is lowered; consequently they are counterbalanced without going to the expense of providing box frames with counterweights.

The floor of the roundhouse is of concrete, built similarly to a sidewalk, and placed on cinders. It is laid out in squares of about 3 ft. to the side, so if any square gets broken, as it is liable to be on account of the heavy pieces handled in a house of this description, it can be repaired at small cost.

The foundations carrying the posts are of concrete and are entirely separate from the floor, so if any settle, the floor will not be disturbed.

On the roof sheathing is laid a built-up roof of 5-ply tar and crushed limestone. The crushed limestone not only adds weight to hold the built-up roof in place, but, being white in color, helps to protect the tar from the rays of the sun. The cost of this roof covering in place was about the same as that of a prepared roofing.

The turntable foundations are supported by piling and are of concrete. The center or pivot foundation is reinforced with rods just above the head of the piles. The circle rail is spiked to short ties laid without any fastenings on the circle wall. The pit is paved with concrete in a manner similar to that in the house and is drained by a 4-in. tile into the catch basin previously mentioned.

The turntable is of the deck type, 75 ft. long, with a live load capacity of 215 tons, and is turned by means of a tractor wheel running on the circle rail and operated by electricity. The steel work of the turntable was built by the American Bridge Co., and installed by employes of t..e Wabash R. R. Co.

There are 70 cu. yds. of cinders removed daily from the cinder pits by means of an electric gantry crane and clamshell bucket, this part of the plant being made by the Case Mfg. Co., of Columbus.

Ohio. There are two cinder pits, each 150 ft. long, and the crane travels on a track between them.

The cost of work is given below in detail; but, as will be noticed, it does not include the value of the old buildings utilized (machine shop, blacksmith and boiler shop and sand house), nor the value of the old machinery and cost of labor for installing it in the machine shop.

42 stall engine house, incl. turntable foundations....	$60,000	
Roofing	2,000	
Heating system with pump, well, etc.	6,220	
Smoke jacks	2,100	
Door anchors	100	
Drainage and sewerage	1,950	
Wiring and lights	1,000	
Grading	600	
Engineering in field	1,000	
Track inside of engine house (value new)	1,675	
Telpher hoist	1,000	
Washout system and motors	6,900	
		$ 84,545
Track between turntable and engine house and labor laying (value new)		$ 1,955
Turntable pit and foundation	$ 3,360	
Turntable	2,430	
Circle rail and track on turntable (value new)	685	
Machinery for operating turntable	1,075	
		7,550
Cinder pit	$ 6,875	
Gantry crane	835	
Machinery for gantry crane	2,950	
Clam-shell bucket (value new)	600	
		11,260
Coaling station (200-ton)		8,775
Sand house and machinery (value new)		2,000
50,000-gal. water tank and fixtures (value new)....		1,100
Three water cranes with water pipes and fixtures, etc. (value new)		1,000
		$118,185

NOTE.—Items with the words "value new" written after them indicate that the material or structure had been formerly used with the old facilities. The amount given is the cost if new.

Cost of a Brick and Steel Building.*—Mr. A. E. Duckham is author of the following:

In the spring of 1907 the writer was called upon to design a building for a wire-glass plant in South Greensburg, Pa., for the Arbogast-Brock Glass Co.; the wire-glass to be made under a new process of Mr. John Arbogast, who is now superintendent of the plant which has been completed. The building, which is 60 x 170 ft., was started (breaking ground) on May 20 and was finished by the author on Aug. 1. This includes the lehr (furnace) foundations.

The foundations up to the level of the ground are of concrete, made of 1 part cement (Portland), 3 parts sand, and 7 parts gravel. They were carried down to clay, which on an average was 3 ft. below the surface of the ground, which was level. As the ground

**Engineering-Contracting,* Apr. 15, 1908.

was marsh-like, the trenches were dug and immediately filled up with concrete, mixed on the board and deposited by wheelbarrow from a plank runway into the bottom. No water was required in the mixing-board for the bottom layers of concrete, owing to the trenches being partly filled with surface water. After standing all night we would find the trenches filled with water in the morning; this we pumped out with an ordinary hand-pump and trench suction hose (about 3 ins. in diameter). At times, it kept one man busy pumping all day, owing to the heavy rains to which we were subject, which kept the ground saturated.

Above the level of the ground the building is of brick. The roof-trusses are of steel, including the purlins. They rest on the pilasters of the wall, and are attached to them by anchor bolts. The latter were set loose in the walls; and, after the erection of the steel, were grouted with cement mortar. This was to facilitate the erection of the steel-work.

The roof was covered as follows: Nailing strips of 2 x 4 in. hemlock were bolted (every 3 ft.) to the steel purlins, and upon them was nailed 1⅝ in. matched yellow-pine sheathing; upon this was laid and fastened Carey's Magnesia Flexible Cement Roofing.

The building was well situated for receiving materials, as it was located 118 ft. from the railroad and 75 ft. from a street. The cement, sand, gravel and brick were obtained from local dealers within a mile of the place; the first three were hauled by wagon (with the exception of one carload of sand), and the last one was shipped in by car on a siding opposite the building, and slipped in by a chute, the railroad track being about 8 ft. above our ground.

The walls between the pilasters are only 9 ins., but the pilasters project 9 ins., thus making an 18-in. pillar or column under each truss to carry the load; the 9-in. wall between acting as a curtain wall. The brick wall was laid complete in cement mortar, no lime being used. The mortar was composed of 1 part of cement and 2⅝ parts of clean river sand. When the building was finished, the mortar was so hard that it was difficult to break it with a hammer. We had some trouble at first with the bricklayers to get them to use this mortar without the addition of lime, as it is not easy to spread. When set up, however, it lasts for all time.

The cement, an American Portland, gave us perfect satisfaction. This was used throughout—in foundations, brick walls and lehr (furnace) foundations. Partly in the lehr foundation we used furnace slag from the steel works in place of gravel, being unable to obtain the latter in time. It was very satisfactory, but required much more water in mixing, which had to be carried from a creek about 100 ft. distant.

The steel half trusses were skidded off the cars onto the ground, brought into the building after the erection of the walls through one of the large doorways on a "buggy," riveted together to form complete trusses, and then raised into position by a gin-pole, block and tackle, and crab (the latter being operated by six men). There were ten steel erectors, and it took them about ten days to

erect the steel-work, including trusses, purlins, lateral bracing (in three bays) and "sag rods." A day or so was lost, however, waiting for tools and material.

On the original plans we figured on regular ventilators or lanterns with side louvres of sheet steel extending the whole length of the ridge of the roof for ventilation; but, at the suggestion of the owners, to save cost, these were omitted, and four ordinary circular ventilators were used along the ridge. As there were many large windows along the sides of the building, as well as the ends, these were considered enough for the purpose. The windows had boxes for pulleys and weights. There were two sash to each window. The bottom sash weighed 39 lbs. including the glass; this was weighed to determine the size of counter-weights.

The 122 squares of roof-covering took one week to lay, nail, cement, and paint. There were five men for three days and two men for six days. Two men (experts) came up on the job, and three ordinary local mechanics were hired. The extra men cost $20.

In unloading the brick from the cars on the railroad track, in one case it took five hours to unload one box car of 12,000 brick with four men (two inside and two outside), with chute; and in another it took 3¾ hours for five men to unload the same car.

The building was not only designed by the author as engineer and architect, but he also had the contract to erect the building complete on the "cost-plus-a-fixed-sum" plan. By this method, the owners saved at least $2,000 figuring on the lowest bids, or about 25 per cent of the net cost (not taking into account the architects and contractors' commission). The building was originally intended to be built at Carnegie (about five miles from Pittsburg), but was finally built at Greensburg (over 30 miles from Pittsburg), where everything, owing to the increased distance from a large city and a river (for sand and gravel), cost more. The bids were figured on the Carnegie location, consequently the percentage showing the amount saved in cost should be increased.

The average lump bid of the contractors was about $11,500, but this was for the Carnegie location. To show the increased cost of the same building at Greensburg, we got a bid on the brickwork from the same man of $1,955 at Carnegie and $2,400 at Greensburg, or an increase of over 22 per cent. Again cement cost $1.75 per barrel at Carnegie and $1.85 at Greensburg, while sand cost 7½ cts. a bushel at Carnegie and 9 cts. at Greensburg.

The detailed cost of the building as built was as follows:

Steel-work	$2,730.00
Lumber, doors and windows, sheathing, etc.	1,283.64
Roof covering (cement roofing felt)	412.50
Cement, sand and gravel	938.04
Brick	738.45
Labor (including common labor, bricklayers and carpenters)	2,175.58
Bolts to fasten nailing strips to purlins	28.88
Hardware	79.54
Ventilators (circular)	18.00
Total	$8,404.63

The cost of the building per cubic foot of space from the ground level to the roof was 3¼ cents. The cost per square foot of floor space was 82.4 cts. The above does not include the architect's fee of 5 per cent or the contractor's fee (of approximately 8 per cent); this would bring the cost per cubic foot up to 3.6 cts., and the cost per square foot up to 93.1 cts.

The building was filled in to a depth of 4 ft. with dry earth and burnt sand (from a foundry nearby). It was originally intended to lay a cement floor upon this, or a brick floor (preferably the latter, as being easier to take up for the additional lehrs); but this was abandoned for the present, until the filling would become well tamped down by walking and by rolling trucks over it.

The lehr walls (foundation) were built by the writer under a separate contract with the furnace contractors. This work he did for $6.50 a cubic yard for the concrete walls (3 ft. under ground and 4 ft. above ground) and 50 cts. a yard extra for excavating the trenches. At this figure, he made 18 per cent profit. There were some advantages and some disadvantages. Under the head of advantages were the facts that his foreman, who was overlooking the main building, also took charge of this work; then for casing or forms for the concrete we used sheathing and lumber afterwards used on the building; under the head of disadvantages were the handicaps of having to carry water for the concrete and that we were held up by the steel erectors, who got in our way. The carpenter work in building the forms for the concrete lehr foundations amounted to 10 per cent of the total labor bill. The total labor bill amounted to 28 per cent of the total cost, and the materials (cement, gravel, slag, and sand) consequently run up to 72 per cent of the total cost. Runways were built of inclined planks, and the concrete was deposited by wheelbarrows directly into the forms and then tamped. The writer believes in rather a wet mix of concrete, tamped enough to bring the water to the surface, and make it liver like (quaking).

Inclined runways and scaffolding of 2-in. plank and doubled 2 x 4-in. studs as posts were also used in the main building to supply the bricklayers with brick and mortar. Up these, common laborers wheeled the material in barrows; thus doing away with the slow and more expensive hod-carriers and ladders. The material used in the construction of the runways and scaffolds was afterward used in the room, so there was but little waste of lumber.

The plans, with the exception of the details, were made on ⅛-in. scale, instead of the usual ¼-in. scale. This smaller scale made it more convenient in the field, and not so cumbersome, especially when there was a strong wind. The writer believes that as small a scale as possible should be used, and all details should be made on a separate sheet on say 1-in. or 1½-in. scale. Figures in all cases should be given instead of depending on the scale. This would remove all doubt and controversy. In fact we should follow the procedure of the bridge drafting room.

In designing the building, no attempt was made at ornamentation, as the owners wanted the building to cost as little as possible; but the writer saw to it that everything was strong and efficient.

The brickwork was laid in English Bond, the strongest kind; and the writer was surprised to find how few of the so-called practical bricklayers knew what it was or how to lay it. Most of them thought that it was Flemish bond—or alternate headers and stretchers—instead of alternate layers of headers and stretchers, which is the English Bond.

Cost of Reinforced Concrete Buildings.—The following is a very brief abstract of a five-page article by Mr. Leonard C. Wason, President Aberthaw Construction Co., in *Engineering-Contracting*, Jan. 13, 1909. [The labor unit costs are rather high. The work was done in New England.]

It is well known that the cost of materials and labor in different parts of the country vary somewhat. Having the unit items all sub-divided into their elementary parts, it is an easy matter after determining the cost of materials in any locality to make the exact corrections to the results obtained on a previous job. Similarly, when a difference in the rate per hour for wages is known, if the same efficiency is obtained from the men it is very easy to make a correction, or if the efficiency varies, judgment must be applied to determine the correct rate to use. It has been the writer's experience that although the rate of wages and cost of materials vary somewhat in different parts of the country, the variations frequently offset one another so nearly that the sum total of the unit cost obtained in one place may be used in another, very seldom needing correction. For instance, within one month, after careful investigation, a bid was made up on a structure at San Juan, Porto Rico, using the same unit costs as for a building in Boston. In the report that is given, the costs relate to strictly first class material and workmanship in every case, as it has been the endeavor of the writer to establish and maintain one standard for all work. In general I would say that the standard mixture for all floors has been either 1-3-6, or 1-2-4 if the floor is subjected to extremely heavy loads and service. Walls are mixed 1-3-6 and columns usually 1-2-4; in some cases where they are very heavily loaded a richer mixture is used. As these mixtures are common to nearly all construction the costs here given may be applied with little danger of error from neglecting the mixture on any work. Of course it can readily be understood that in the large number of jobs which have entered into the averages given, there being as many as 18 in the case of beam floors, different methods of conducting the work have been used and many different foremen. Therefore, while the general average is doubtless safe for any work of an average character, some latitude may be allowed the judgment in determining whether any specific case is likely to be difficult, easy or average. The writer has found quite a difference, for instance, in cost of identical work handled by different foremen, due to the personal equation of their painstaking supervision and ability.

Cost of Columns.—The following costs are the average of 9 buildings:

	Per cu. ft. of concrete.
Cement	$0.085
Sand and stone	0.049
Labor on concrete	0.096
General labor	0.027
Team and miscellaneous	0.021
Plant	0.023
Total, exclusive of steel and of forms	$0.301

The cost of forms per square foot of concrete surface encased was as follows:

	Per sq. ft.
Lumber at $22 per M	$0.036
Nails and wire	0.001
Carpenter labor	0.082
Total	$0.130

This includes all necessary posts and staging, also wheelbarrow runs for placing the concrete.

Cost of Beam Floors.—The average cost for 18 buildings was:

	Per. cu. ft. of concrete.
Cement	$0.106
Sand and stone	0.063
Labor on concrete	0.111
General labor	0.020
Team and miscellaneous	0.025
Plant	0.024
Total, exclusive of steel and of forms	$0.354

The cost of forms per square foot of concrete surface covered was:

	Per sq. ft.
Lumber at $22 per M	$0.045
Nails and wire	0.002
Carpenter labor	0.070
Total	$0.116

Cost of Flat Slab Floors.—The average cost of 3 buildings was:

	Per cu. ft. of concrete.
Cement	$0.096
Sand and cement	0.070
Labor on concrete	0.097
General labor	0.009
Team and miscellaneous	0.019
Plant	0.024
Total, exclusive of forms	$0.315

The cost of forms was:

	Per sq. ft.
Lumber at $22 per M	$0.038
Nails and wire	0.002
Carpenter labor	0.071
Total	$0.111

Cost of Concrete Slabs Between Steel Beams.—The average cost for 13 buildings was:

	Per cu. ft. concrete.
Cement	$0.128
Sand and stone	0.068
Labor on concrete	0.102
General labor	0.019
Team and miscellaneous	0.024
Plant	0.017
Total, exclusive of steel and of forms	$0.359

The cost of forms was:

	Per sq. ft.
Lumber at $22 per M	$0.032
Nails and wire	0.002
Carpenter labor	0.061
Total	$0.095

Cost of Walls.—The average cost of concrete walls (above grade) for 17 buildings was:

	Per cu. ft. concrete.
Cement	$0.073
Sand and stone	0.076
Labor on concrete	0.090
General labor	0.016
Team and miscellaneous	0.025
Plant	0.019
Total, exclusive of steel and of forms	$0.301

The cost of forms was:

	Per sq. ft.
Lumber at $22 per M	$0.036
Nails and wire	0.002
Carpenter labor	0.085
Total	$0.128

Cost of Foundation Walls.—The average cost for 14 buildings was:

	Per cu. ft. concrete.
Cement	$0.080
Sand and stone	0.062
Labor on concrete	0.076
General labor	0.015
Team and miscellaneous	0.019
Plant	0.017
Total, exclusive of forms	$0.269

The cost of forms was:

	Per sq ft.
Lumber at $22 per M	$0.033
Nails and wire	0.002
Carpenter labor	0.068
Total	$0.103

Cost of Footing and Mass Foundations.—The average cost for 10 buildings was:

	Per cu. ft. concrete.
Cement	$0.071
Sand and stone	0.077
Labor on concrete	0.045
General labor	0.007
Team and miscellaneous	0.007
Plant	0.021
Total, exclusive of forms	$0.229

The cost of forms was:

	Per sq. ft.
Lumber at $22 per M	$0.034
Nails	0.002
Carpenter labor	0.057
Total	$0.093

Cost of Labor on Reinforcing Steel.—Table XI omits entirely the first cost of the material. After it is received at the site of the work in the shape sold by the manufacturer, these prices cover the cost of fabricating into units for columns or beams, bending the stirrups, placing and all incidentals whatsoever prior to the actual embedding in concrete. In the case of the highest cost, a coal pocket, there was very limited storage space, 1¼-in. bars had to be bent diagonally so as to pass over the top of the support at columns, and there were numerous stirrups, all of which had to be made by hand. The job was too small to justify any mechanical arrangement for bending or for handling material. The next highest, office building, Portland, Me., there was a sufficient amount to require proper machinery. The hoops for columns were all welded. The vertical bars were all wired inside of these hoops. There was a mushroom head of bent and circular bars wired together at the top and great numbers of long bars of small section spread in all directions over the floor. The lowest price, filter at Lawrence, was made entirely of straight bars placed loose, the only expense being cutting them in a hand shear to length and placing them.

TABLE XI.—STEEL.

Location.	Weight. Tons.	Cost of handling.	Cost per ton.
Office building, Portland, Me.	324½	$5,115.32	$15.76
Fire station, Weston, Mass.	8½	40.26	4.74
Mill, Chelsea, Mass.	65¼	548.81	8.41
Coal bins, Dalton, Mass.	8½	61.75	7.26
Dam, Auburn, Me.	55	506.76	9.18
Filter, Warren, R. I.	19	102.59	5.40
Tank, Lincoln, Me.	8½	69.38	8.16
Tar well, Springfield	15½	59.21	3.82
Monument, Provincetown	24½	136.84	5.58
Mill, Greenfield	92¾	1,232.01	10.20
Machine shop, Milton, Mass.	20¼	177.16	8.75
Coal pocket, Lawrence, Mass.	28	461.16	16.47
Mill, Southbridge	53½	142.76	2.67
Mill, S. Windham, Me.	293	3,079.60	10.51
Mill, Attleboro, Mass.	49½	286.02	5.78
Garage, Newton, Mass.	20	86.55	4.33
Mill, Southbridge, Mass.	30	100.03	3.34
Coal pocket, Hartford, Conn.	195	2,316.60	11.88
Filter, Lawrence, Mass.	44½	112.84	2.54
Warehouse, Portland, Me.	62	462.99	7.47
Standpipe, Attleboro, Mass.	199½	1,547.00	7.75
Highest	...	....	16.47
Lowest	...	....	2.54
Average of 21	...	....	8.52

Cost of Reinforced Concrete Building Construction.*—Mr. T. Herbert Files is author of the following:

The costs here given are those of labor only, as labor costs are usually the unknown ones in estimating, the material costs being easily obtained from the schedule of quantities and the market prices.

These costs are taken from different work which the writer has been on and are known to be correct for that kind of work. They are not obtained from rough figures after the work was finished, but from carefully kept cost records. All of the costs are from jobs consisting of a number of buildings.

The cost analysis was kept in the following manner. Each job had a cost keeper whose only duties were those of keeping the average weekly cost of the different work of construction. The distribution of the time was taken either from foreman's reports or from time cards. Most of the costs given in this article are obtained by means of time cards.

Time cards are rather difficult to get from the ordinary labor employed on construction work, but this difficulty was overcome by having the foreman of the labor gangs make out cards for each man in his crew. The carpenters and better class of laborers made out their own cards. Each man had to pass in a time card as he checked out at the timekeeper's window at night. In this way the record of each man's time and how it was spent, was passed into the office each night, and no special men were lost, as usually happens when the distribution is taken from foremen's cards.

*_Engineering-Contracting_, Apr. 7, 1909.

The cost keeper would go over these cards the next day and enter the totals of the labor of each class of work on the cost keeping sheets. The record was divided into different accounts, one for each division of the work, such as excavation, concreting, forms, floor finish, steel, etc. All time was charged against its proper account in such a way as to show the date, kind of work, total time, and wage rate, as shown by the accompanying form.

The total number of hours in the analysis was checked up each day with the total number of hours on the timekeeper's sheets. At the end of each week the total cost of each kind of work for the week and the unit cost were figured up and a summary made of the totals of the different accounts. This total was then compared with the pay-roll. If everything has been carried through correctly, the two totals should check within a few dollars. They will not check exactly, as average wage rates are used in the cost keeping.

Wages.—As cost figures do not mean much unless the rates of wages are known, the average rates paid will be given. They are as follows:

Common labor, as used in excavating, unloading materials, and unskilled work, 17½ cts. per hour; foreman, 30 cts.; concrete labor, 19 cts. per hour; foreman, 40 cts.; steel labor, 25 cts. per hour; foreman, 30 cts.; form labor, used for stripping and rough carpenter work, 30 cts.; carpenters 41 cts. per hour, and foreman, 50 cts.

Cost of Unloading Materials.—Cement is usually unloaded by laborers carrying the bags on their shoulders from the car, or by wheeling in wheelbarrows. If a car can be unloaded direct from the car into the storage shed, with very little carrying, six men can unload 600 bags equivalent to 150 bbls., in 3 hours, at a unit cost of 2 cts. per bbl. If unloaded by wheelbarrows with a distance of 100 ft., it will cost 4 cts. per bbl., but may run up to 5 cts. or 6 cts. if the men are not handled in the proper manner.

Sand and gravel will cost on an average of 8 cts. per cu. yd. for unloading, laborers shoveling it from the car to the storage pile nearby. The cost varies from 6 to 10 cts., depending upon conditions.

Reinforcing steel bars can be unloaded at a cost varying from 35 cts. to $3.00 per ton, depending upon the carrying distance. Here are some actual costs:

Unloading ¾ in. x 20 ft. twisted steel, from box cars and piling it on ground beside car 32 cts. per ton.

Unloading from gondola cars, carrying 300 ft. and piling on racks in steel shed, $3.00 per ton.

The unloading of lumber differs considerably in cost, same depending upon the distance carried and the size of the sticks. It was found, however, from our records that it cost from 70 cts. to $1.00 per 1,000 ft. B. M. to unload, haul 200 ft. and pile, form sheathing.

Form Work.—The cost of form work is the most difficult cost to get in reinforced concrete construction. This is especially so in regard to the making of forms, as the work on construction jobs is usually done in such a manner that it is hard to distribute the costs

properly and have the correct amount of work done, reported. The cost work here referred to was not started in the best way to give good costs of the making of forms and for that reason the costs of making forms will not be as complete as might be. The unit costs were figured on the number of square feet of form surface in contact with the concrete.

The following are some of the labor costs of forms made in a field carpenter shop, which consisted of two saw machines, a planing and a boring machine, with a shop foreman in charge.

	Per sq. ft. of surface.
Columns	cts.
Girders and beams	5 cts.
Floor panels	2 cts.
Wall panels	3 cts.

The cost of setting forms for the floors, which included time spent in the moving of the forms from one floor to another, erecting and setting the forms of columns, beams, and floor panels and the falsework supporting them, was figured per sq. ft. of floor surface. The costs of different floor set-ups varied, because the men at first were unskilled and not well organized. From 1,300 to 1,800 sq. ft. of floor were set up in a day. These costs ranged from 13 cts. per sq. ft. for the first set-up to 4.7 cts. for the roof set-up, making an average of 8.4 cts. per sq. ft.

The stripping of the floor forms cost from 2.5 cts. to 1.5 cts. per sq. ft., or an average of 1.9 cts. per sq. ft. of floor. This makes the cost of setting up and stripping of forms for floors average 10.3 cts. per sq. ft. of floor.

The curtain walls, between columns, were put in place after the floors and cost from 6 to 10 cts. per sq. ft. of form surface for setting up, or an average of 8 cts. The cost of stripping these was ½ ct. per sq. ft. Partition walls and outside plain walls cost from 4 to 8 cts. per sq. ft. of form surface or an average of 5 cts. for setting and ½ ct. per sq. ft. for stripping.

Reinforcing Steel.—The steel used for reinforcing was twisted rods. The column cages, beam and girder reinforcements were made up into units in the steel yard. From there they were carried and hoisted to the different floors, as they were made ready for concreting, and were put in place by the steel gang before concreting. The floor steel was placed as the floor was concreted.

The cost of the steel work is divided as follows:

	Per ton.
Unloading	$ 2.00
Making up steel	5.50
Carrying	1.75
Placing	1.00
Total	$10.25

Concreting.—The labor costs in concreting vary a great deal with the plant and method of conveying. On this work, the concrete was machine mixed, the materials being run into storage hoppers

over the mixer, by a self dumping car, on an inclined track, from the material pile, where it was loaded by hand. The concrete after being mixed, was raised to the proper floor by a hoist, which dumped automatically into a hopper. From this hopper the concrete was wheeled to the desired location by means of concrete carts. The greatest wheeling distance was 350 ft. and the least 50 ft., making the average distance 200 ft. The costs of concreting columns and floors ranged from 2.8 cts. to 4.2 cts. per cu. ft., or an average cost of 3.5 cts. per cu. ft.

In concreting footings, the material was moved to the mixer by means of wheelbarrows instead of self dumping cars, and wheeled to the desired location over plank runs. Under these conditions the cost of concreting was 5 cts., with the carrying distance the same as for the floors.

Cost of Reinforced Concrete Factory.*—Mr. D. L. C. Raymond gives the following relative to a building erected in 1907 at Walkerville, Ontario. It is a two story factory, 100 x 100 ft., with 18 ft. clearance on the first floor and 12 ft. on the second. It is skeleton type of construction, 16 x 16 ft. floor panels, and 6-in. curtain walls. Steel rods were used for reinforcement with wire mesh in the slabs. A 1:2:4 mixture was used, the mortar finish on the floors being 1:2.

The columns and beam forms were 2-in. dressed pine, supported by 4 x 4 stuff. The floor forms were 1 in. laid on 2 x 4 pieces spaced 18 ins.

The men were all green at the work. There were 847 cu. yds. of concrete, the cost of which was as follows:

	Total.	Per cu. yd.
Materials:		
Cement at $2.05 per bbl.	$ 3,314	$ 3.91
Sand and gravel at $1.25 per cu. yd.	1,054	1.25
Reinforcement at $55 per ton	2,314	2.73
Lumber for forms at $27 per M.	4,944	5.84
Nails	107	0.13
Total materials	$11,733	$13.86
Labor:		
Building runs, mixing and hoisting concrete	$ 872	$ 1.03
Placing and tamping concrete	562	0.66
Placing reinforcement	221	0.26
Stripping and cleaning forms, etc.	380	0.45
Carpenters building and setting forms	2,010	2.38
Superintendence	714	0.84
Tools and depreciation of plant	338	0.40
Total labor	$ 5,097	$ 6.02
Grand total	16,830	19.88

It will be noted that no salvage is allowed for the lumber, and that 216 ft. B. M. were used per cu. yd. of concrete. The carpenter work on the lumber cost $11 per M. The cost of stripping lumber and cleaning up amounted to a little more than $2 per M.

There were 100 lbs. of reinforcement per cu. yd., and the labor of placing it was only a trifle more than ¼ ct. per lb.

*Engineering-Contracting, Apr. 29, 1908.

This building contained about 320,000 cu. ft. of space. Hence the cost of the concrete alone was 5¼ cts. per cu. ft., which is a low cost. The cost per square foot of floor area (2 stories) was 84 cts., not including windows, etc.

Cost of a House of Separately Molded Concrete Members.*—The construction of a kiln house of separately molded reinforced concrete columns, girders and slabs for the Edison Portland Cement Works at New Village, N. J., was described in our issue of Oct. 2, 1907. (See also "Concrete Construction," by Gillette and Hill.) This article gave for the first time costs of molding and erecting separately molded concrete structural members for building work. Since it was published the same company has built a cement storage house for which the columns, girders and roof slabs were separately molded and erected. In a paper by Mr. W. H. Mason, superintendent Edison Portland Cement Works, some of the costs of this later work were given. We give these costs in different form and more fully analyzed in the following paragraphs.

The storage house is 144 x 360 ft., in plan with a clear height of 30 ft. The exterior walls are of retaining wall section, they having to take the thrust of the stored cement, and they were built in place. Between walls are five longitudinal rows of columns; the rows are spaced 24 ft. apart and the columns in each row are 12 ft. apart. Transverse roof girders 12 ft. apart cap the columns and carry a roof of 6 x 12 ft. x 4-in. slabs. For column footings 5 x 5 x 5-ft. plain concrete cubes with 20-in. square sockets molded in their tops were used.

Materials and Labor.—The concrete used was a 1:6 mixture, using crushed run stone, all of which would pass a ¾-in. screen. The Edison company furnished both cement and stone, charging up the cement at $1 per barrel and the stone at 60 cts. per cu. yd. The lumber, of which 7,000 ft. B. M., were used, cost $27 per thousand. The reinforcing steel, of which 201,400 lbs. were used, cost delivered 2.03 cts. per pound. A force of 23 men was employed; eleven of them were classed as carpenters at an average wage of 24 cts. per hour and 12 as laborers at an average wage of 15 cts. per hour.

Casting Floor and Plant.—The casting floor on which the columns, girders and slabs were molded, was located some half a mile from the building. A ½ cu. yd. Ransome mixer was set up under the mill conveyor which carries crushed cement rock for cement making to the stock house and from this conveyor the stone was chuted directly into the mixer stock bins as wanted. The mixer discharged directly into 3 cu. yd. cars which ran out on a track between casting floors on each side. The casting floors consisted of trowel finished concrete slabs 4 or 5 ins. thick laid on a 4-in. sub-base of compacted cinders. These casting floors cost, Mr. Mason states, 4 cts. per square foot. So far as possible, members were cast side by side and in tiers so as to reduce floor space and form work. The concrete cars discharged by spout directly into the molds, the mixture being made wet enough to flow easily.

**Engineering-Contracting*, Mar. 18, 1908.

Molding Columns.—There were 141 columns, having 18 x 18-in. shafts 32 ft. long with two triangular brackets at the top for girder seats, and each column contained very closely 2.8 cu. yds. of concrete and 275 lbs. of reinforcement or closely 98 lbs. of steel per cubic yard of concrete. These quantities are computed from drawings. The construction of the forms for molding the columns is shown by Fig. 7. Each complete form contained about 535 ft. B. M. of lumber and seven were used for molding 141 columns and were still in good condition after the work. The seven molds contained about 3,745 ft. B. M. of lumber and molded 141 × 2.8 = 395

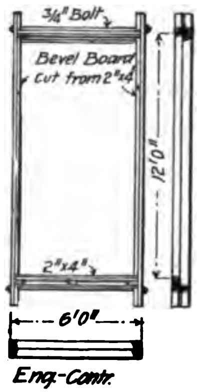


Fig. 7.

cu. yds. of concrete, so that the amount of form lumber used per cubic yard of concrete molded was about 9.7 ft. B. M. The costs of molding per column and per cubic yard were as follows:

Item.	Per col.	Per cu. yd.
Steel reinforcement	$ 7.57	$2.70
Concrete materials	5.48	1.96
Labor, carpenters	4.27	1.52
Labor, concrete and steel	1.95	0.70
Total cost	$19.27	$6.88

Molding Girders.—There were 187 girders, each 12 x 26 ins. x 24 ft. and each containing 1.9 cu. yds. of concrete and about 320 lbs. of steel or about 168 lbs. per cubic yard of concrete. A complete girder form is shown by Fig. 8. A complete form contained approximately 370 ft. B. M. of lumber and five forms, or 1,860 ft. B. M., were used for molding 187 girders, or about 5.2 ft. B. M. per cu. yd. of concrete in girders. It should be noted that many of the girders were molded between other girders without using any

wooden forms at all. The average cost of molding a girder complete was as follows:

Item.	Per girder.	Per cu. yd.
Steel	$ 5.53	$2.91
Concrete material	3.51	1.90
Carpenter labor	2.26	1.18
Labor, mixing, placing, etc.	1.34	0.70
Totals	$12.64	$6.69

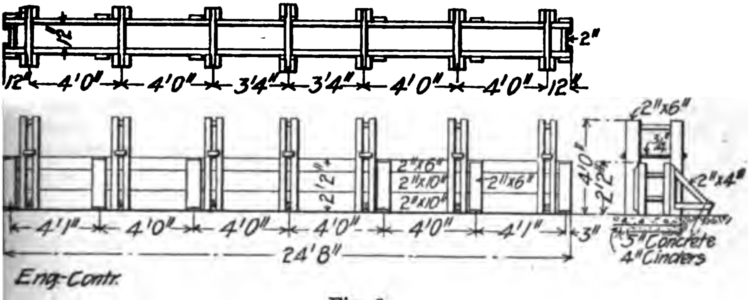


Fig. 8.

Molding Roof Slabs.—The roof slabs were 6 x 12 ft. x 4 ins. and each contained 0.88 cu. yds. of concrete and about 83 lbs. of reinforcing steel or about 95 lbs. of steel per cubic yard of concrete. The slabs were molded in tiers, using the form shown by Fig. 9, made 8 ins. deep so as to be clamped onto each slab in molding the slab above. There are about 52 ft. B. M. in a slab form, as 28 forms molded 720 slabs, about 2⅛ ft. B. M. of form lumber were required

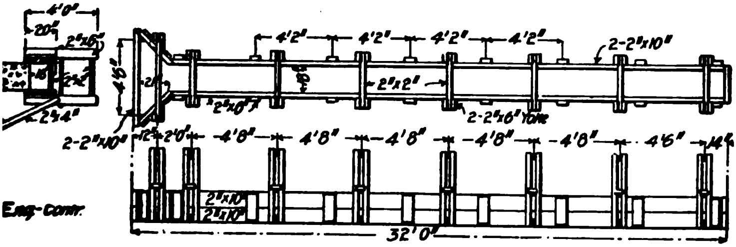


Fig. 9.

per cubic yard of concrete. The cost of molding roof slabs was as follows:

Item.	Per slab.	Per cu. yd.
Steel	$1.69	$1.92
Concrete material	1.85	2.10
Carpenter labor	0.423	0.48
Labor	0.405	0.46
Totals	$4.368	$4.96

Each slab covered 6 x 12 = 72 sq. ft. of roof, so that the cost of molding was 6.06 cts. per sq. ft. or $6.06 per 100 sq. ft.

In casting columns, girders and slabs side by side and in tiers in contact the fresh concrete was prevented from adhering to the member already molded by coating the contact surface of the molded member with two coats of ordinary whitewash. This method proved far superior to using paper, as had been done in previous work. The paper stuck to the concrete so fast that it was difficult to remove it. It should be noted also that in the preceding cost figures the cost of form lumber is apparently included in "carpenter labor." There was 7,000 ft. B. M. of form lumber at $27 per M. ft. required for molding 1,048 members, or about 1,384 cu. yds. of concrete. The cost of form lumber per cubic yard of concrete was, therefore, $189 ÷ 1,384 = 13.65 cts.

The labor cost of erecting the molded concrete members with a Browning locomotive crane was as follows:

	Per cu. yd.
Columns	$2.83
Girders	1.57
Roof slabs	1.75

The details of this cost of erection and the methods are given in Gillette and Hill's "Concrete Construction."

Comparative Cost of Constructing Two Identical Reinforced Concrete Buildings—One of Separately Molded Members and One of Members Molded in Place.*—Mr. Mason D. Pratt is author of the following:

In 1904 the Central Pennsylvania Traction Co. of Harrisburg, Pa., built a car barn and a repair shop of reinforced concrete, probably the first buildings in this country built entirely of this material for this purpose. The buildings are one story in height and were constructed in the usual manner by erecting wooden forms and casting all concrete work in place. The same company has just completed a second barn adjacent to the one above described of the same dimensions as the first barn, viz.: 75 ft. wide by 360 ft. long. The last barn is also of reinforced concrete, but owing to conditions which seemed favorable for the purpose, an entirely different mode of construction was followed. All of the members for that portion of the building above the foundation and floors, including columns, beams, wall and roof slabs, were separately molded on the ground and afterwards erected by means of a traveling stiff-leg derrick. This method of construction proved economical and owing to the close similarity of the two buildings in size and general design it is possible to make an accurate comparison of the costs. In describing the two buildings, Barn *A* refers to the original building and Barn *B* the last one erected.

Barn *A* was built on ground which was from 2 to 10 ft. below the floor level. The column footings were placed on solid ground 6 to 12 ins. below the sod and carried up within 1 ft. of floor level, the ground being filled in after the building was under roof. In general

Engineering-Contracting, Jan. 19, 1910.

plan the building had three rows of non-reinforced hexagonal columns spaced 15 ft. centers longitudinally and 37 ft. centers transversely. The roof consisted of transverse beams, resting on the columns, longitudinal purlins and a 3-in. slab cast in place, the columns being connected longitudinally with beams 6 ins. thick and 2 ft. deep. After the forms were removed from this skeleton the three longitudinal walls were filled in place. Provision was made for future extension laterally by casting brackets in the columns to support roof girders for an adjacent bay. The barn also had a wing 16 ft. wide and 90 ft. long, containing barn foreman's office, lockers and lavatory for the use of motormen, conductors and barn men.

Concrete for this building was mixed in a rotary batch mixer, into which the aggregate was dumped directly from wheelbarrows, and the concrete distributed from the mixer to the job in wheelbarrows by means of runs and an elevator operated by a power hoist.

Barn *B* was built entirely independent from Barn *A*, the first wall being placed 37 ft. beyond the wall of Barn *A*, thus permitting the increase of the plant by one addition bay in the future by simply adding a roof between the two buildings. Column spacing was made the same as Barn *A*, but the columns were square. In order to get roof slabs of a size which could be conveniently handled, the roof beams were spaced 10 ft. centers and alternated in the two bays. Thus on the outer walls a roof beam came at every other column, while on the center wall each column carried a beam and a longitudinal beam between columns supported the ends of two roof beams. The roof proper consisted of slabs, 3½ ins. thick, 10 ft. long and 6 ft. and 7 ft. wide, which were laid directly on the roof beams. Two slabs at the center of every alternate 10 ft. bay were omitted to allow placing skylights. The walls were 6 ins. thick, as in the case of Barn *A*, but were made up of slabs of various sizes. These slabs were all tongued and grooved, as were also the columns. Three-eighths of an inch was allowed for all joints, the horizontal joints being mortared as the work was laid up and the vertical joints filled and pointed after everything was in place. A small percentage of reinforcement was placed in all slabs as an insurance against breakage in handling.

The concrete for this building was mixed in the same mixer used on Barn *A*, located at a central point, the materials being moved in wheelbarrows as before.

Barn *A* had about 290 ft. of open pits under each track, 60 ft. of the front end of each bay being paved with granolithic floor and used as space for washing cars. Barn *B* had the same arrangement in one bay, the other bay, which was intended for storage purposes only, had granolithic floor from end to end. The ground on which Barn *B* was built had been filled in with various materials, mostly cinder from a nearby steel plant, and excavations had to be made for all foundations. In the figures given below, all labor for excavation in both buildings is omitted. In Barn *B* each column had a separate footing as in Barn *A*, which, however, was carried to a point 15 ins. above floor level, and provided with a pocket to

receive the column. A layer of sand was put in each pocket to give the column good bearing and to adjust height. A beam 12 ins. wide and 2 ft. deep connected these footings, being cast at the same time with the footings.

The tracks were laid in the storage bay and the granolithic floor cast in place at the time of starting excavations for the foundations, and as soon as the floor was in place the casting of beams, columns and slabs began. The beams and columns were nested by casting the alternate pieces a suitable distance apart, and after removing the forms these became the forms for the intermediate pieces. The slabs were cast in piles, the ends being offset to enable rapid handling. The pieces were separated by means of 40-lb. waxed manila paper. No difficulty whatever was experienced during the erection in separating. In some instances soap was used, but the results were not as satisfactory and the cost was higher than with the paper. The surface of the pieces formed by paper separation showed a close, smooth, dull surface, except for the wrinkles formed by the paper, which was not heavy enough to prevent wrinkling. The paper was also responsible for other defects in the surface finish, owing to the mortar running in between joints where the paper overlapped and forming thin slivers. The paper was easily removed with water from a 1-in. hose, with nozzle ¼ in. The top surfaces of all pieces, of course, were troweled. This gave a rather variegated wall surface to the structure, but a coat of cement wash using a thin mixture of about equal parts of cement and limestone dust applied with whitewash brushes produced a fairly uniform appearance. This method of construction involved the use of slightly more reinforcing steel and a larger yardage of concrete, but the saving in forms, lumber and carpenter work was more than sufficient to pay for this difference and the additional cost of derrick and erection labor.

The number of loose pieces required was 1,400. These were completely erected in 33 working days, with a loss of only three slabs from breakage.

The derrick used was a standard stiff-leg with 60-ft. boom and 38-ft. mast, mounted on a truck so that it could be moved around the work. Power was furnished by a regular street railway motor through a gear bolted to the flywheel on the driving shaft of a two-drum hoist, the motor being equipped with standard street railway controller and suitable resistance coils. A traction company motorman operated the hoist and a rigger crew placed the material. The heaviest pieces handled were the roof beams, which weighed 7½ to 8 tons. A number of special devices were used to handle the various pieces. For the heavy beams a loop was formed at the quarter points by bending a reinforcing rod, bringing it flush with the top of the beam and scooping out a portion of the concrete while green, and a special hook used to engage this loop. These hooks entered the slotted ends of a steel spreader. The rig was thus adjustable for variable spacing of the loops and for balancing. The slabs were handled by means of slings, holes being formed in

TABLE XII.—COST OF CONCRETE IN SEPARATELY MOLDED CONCRETE CAR BARN.

BARN *B*.

Foundations and Floors, 710 cu. yds.:

	Total.	Per cu. yd.
Materials:		
Stone at $1.25 cu. yd.	$ 856.00	$ 1.20
Sand at $1.30 cu. yd.	432.00	.61
Cement at $1.15 bbl.	1,082.50	1.53
Steel	120.00	.17
Lumber	633.00	.89
Tools	100.00	.14
Total	$ 3,223.50	$ 4.54
Labor:		
Placing reinforcement	$ 19.00	$ 0.03
Forms	771.00	1.09
Concreting	1,015.00	1.43
Total	$ 1,805.00	$ 2.55
Total materials and labor	$ 5,028.50	$ 7.09

Building above Foundations, 948 cu. yds.:

	Total.	Per cu. yd.
Material:		
Stone at $1.28 cu. yd.	$ 1,085.00	$ 1.16
Sand at $1.30 cu. yd.	546.00	.58
Cement at $1.15 bbl.	1,735.00	1.86
Steel	1,755.00	1.87
Tools	140.00	.24
Lumber	220.00	.15
Total	$ 5,481.00	$ 5.86
Labor:		
Forms	$ 818.00	$ 0.87
Bending and placing reinforcement	360.00	.39
Concreting	1,152.00	1.23
Erection	1,776.00	1.89
Pointing and cement wash	617.00	.66
Total	$ 4,723.00	$ 5.04
Total labor and materials	$10,204.00	$10.90
Totals, 1,648 cu. yds.	15,232.50	9.245

Area covered by building, 360 × 75 ft. = 27,000 sq. ft.
Cost of foundations and floors.....18.5 cts. per sq. ft.
Cost of building.................38.0 cts. per sq. ft.

Total ....56.5 cts. per sq. ft.

TABLE XIII.—COMPARISON OF COST BETWEEN CAR BARNS, SEPARATELY MOLDED AND CAST IN PLACE.

(Average including Foundations and Superstructure.)

	Per cu. yd. Barn A. (Cast in place.)	Per cu. yd. Barn B. (Separately molded pieces.)
Materials:		
Stone, sand and cement	$ 3.480	$3.480
Steel reinforcement	.915	1.140
Lumber	1.335	.480
Paper	......	.040
Tools, wheelbarrows, etc.	.145	.145
Total	$ 5.875	$5.285
Labor:		
Carpenters	$ 3.250	$0.965
Bending and placing steel	.095	.230
Concreting	2.210	1.685
Erection	......	1.080
Total	$ 5.555	$3.960
Total cost per cu. yd.	$11.430	$9.245
	9.245	
Dif. in favor Barn *B*	$ 2.185	

the slabs with a short section of ¾-in. gas pipe for receiving bolts. In setting up the side walls, these holes were used to fasten 3 x 4-in. sticks on each side of the three wall slabs of each bay, thus keeping them in line, and by means of props, in a vertical position until erection had proceeded far enough to remove them.

Table XII gives complete detailed cost of all the concrete work in Barn *B*.

Table XIII is a comparison of the average costs of all the concrete work on Barns *A* and *B*, the figures covering all charges except general supervision. The concrete aggregate is put at same figure in each to eliminate any difference in unit cost of these materials. The mix was practically the same in each, the largest percentage being 1:2:4. Unit costs for labor were the same in both cases, viz.: ordinary labor, $1.25 per day, and carpenters, $2.50 per day.

It will be noted more steel was required in *B*, but very much less form material and labor. The roof of Barn *B* required more concrete, as all beams and slabs had to be treated as simple members, whereas in Barn *A* full advantage was taken of the T sections. Making full allowance for these differences the actual cost of the concrete structure of Barn *A* over Barn *B* was 15 per cent. Both buildings were constructed by day labor from plans made by the writer and under his direct supervision.

Cost of Metal Forms For Concrete Building Work.*—In *Engineering-Contracting* for Sept. 16, 1908, we describe a system of

**Engineering-Contracting*, Feb. 10, 1909.

metal column and floor forms for concrete building work that had been worked out by Mr. W. L. Caldwell of Canton, Ohio. In a paper read at the recent annual convention of the National Cement Users' Association Mr. Caldwell gives some estimates of the cost of these forms which are of interest. These costs are based on a 16-in. square column, with a girder beam 8 ins. wide and 18 ins. deep below floor slab, and with the lateral beams 6 ins. wide and 12 ins. deep, and floor slab 4 ins. thick.

For a structure of this character, Mr. Caldwell recommends the use of 10-gage material for the angles at the four corners of the columns, 14-gage for the lining of the columns, 14-gage for the girder boxes, 16-gage for the lateral beam boxes and 18-gage material for the channel boards forming the intercolumn area for carrying the floor slab, with all necessary reinforcing angles, bolts, etc., to set up the work complete ready for receiving the concrete. The costs are as follows:

Column centering per lineal foot	$1.75
Girder centering per lineal foot	1.00
Lateral beam centering per lineal foot	0.50
Floor area per square foot	0.13½
Adjustable girder and beam box posts per lin. ft.	0.05

Throwing the cost of all of these items against the floor area, the average is about 45 cts. per sq. ft.

This price is arrived at by taking a building 50 x 100 ft. with 28 columns and 18 bays or intermediate column spaces, each space or bay containing 237 sq. ft., in round numbers, each bay divided by two intermediate cross beams, or three spans to each bay. These figures will vary somewhat with the different types of buildings but will give, it is stated, a fair idea of the average cost.

Under ordinary conditions these centers can be erected at a cost of approximately 1¾ cts. per sq. ft. for labor.

Cost of Concrete Building Blocks.—Mr. L. L. Bingham gives the following data. Letters were sent (1905) to more than a hundred makers of concrete blocks in Iowa. Most of the replies gave data relating to blocks for walls 10 ins. thick. The average cost per square foot of blocks for a 10-in. wall was:

	Cts.
Sand	2.0
Cement, at $1.60 per bbl.	4.5
Labor, at $1.83 per day	3.8
Total, per sq. ft.	10.3

The labor of making the blocks includes mixing, molding, sprinkling, piling and re-piling during or after curing. The average output per man was 48½ sq. ft. (1⅚ cu. yds.) per day.

The 10⅓ cts. however, does not include all costs of manufacture, for it does not include interest, depreciation and repairs, purchase of improved machinery, superintendence and office expense. One maker who turned out 20,000 blocks (40 car loads) had a general expense of nearly 5 cts. per sq. ft., besides the above given 10⅓ cts. The selling price of 10-in. blocks averaged 21 cts. per sq. ft. of wall.

Cost of Concrete Buildings, References.—For further data on this subject consult "Concrete Construction" by Gillette and Hill.

Weight of Steel in Buildings.—Mr. H. G. Tyrrell states that weight of steel for buildings not more than 11 stories high is approximately as follows per sq. ft. of floor area:

	Per sq. ft. Lbs.
Apartment houses and hotels, with outside frame..	14
Apartment houses, without outside frame..........	9
Office buildings, with outside frame...............	23
Office buildings, without outside frame............	15
Warehouses, with outside frame....................	28
Warehouses, without outside frame................	18

Mr. Edward Godfrey gives the following:

The Phipps Power Building, Pittsburg, Pa., is 100 x 100 ft., 10 stories high, the first three stories being 24 ft., the rest being 13 ft. floor to floor. The live load was assumed at 250 lbs. per sq. ft. The total weight of steel and castings was 5,742,500 lbs., or 3.5 lbs. per cu. ft. of volume of building. Of this weight, 1,829,400 lbs. were in the columns, and 305,500 lbs. in the 38 cast iron column bases.

The following is the weight of steel in other Pittsburg buildings:

	Lbs. per cu. ft.
Arrott Building	2.8
Farmers Bank Building.........................	2.3
Empire Building	2.1
Oliver Building	1.8

Mr. J. S. Branne gives the following estimate of the cost of the steel framework of an office building. The building is 50 x 100 ft., 16 stories high in the front and 13 stories high in the rear. The first story is 17 ft. high, and all others are 12 ft. high from floor line to floor line. All curtain walls (outside walls) are 13 ins. thick; inside tile partitions 4 ins. thick; floors of concrete. Live loads are assumed at 60 lbs. per sq. ft.; dead loads are 75 lbs. per sq. ft. Using outside dimensions, there are 745,000 cu. ft. in the building, and the steel weighs 795 tons, or 2.13 lbs. per cu. ft. of building. The price of the steel is estimated at 3 cts. per lb. in place.

Weight of Park Row Bldg., New York.—The main part is 26 stories high, surmounted by two 4-story towers. The area covered is 15,000 sq. ft. It rests on 3,500 piles. The basement was excavated 34 ft. below the street level.

The weight of the building is:

	Tons.
Steel	9,000
Masonry and other materials..................	56,200
Total	65,200

The estimated cost (in 1906) was $2,000,000.

The total height from street level to top of cupolas on towers is 386 ft. The first story is 17 ft. high in the clear, the second is

13 ft., the third and fourth are 12 ft., the fifth is 11 ft., the rest are 9 ft. 11 ins. in the clear.

Weight of Steel Dome.—The steel dome of the Emporium building, San Francisco, is 102 ft. diameter and 52 ft. high, su mounted by a "lantern," 22½ ft. diameter and 15 ft. high. The weight is 200 tons.

Weight of Largest Steel Dome.—The largest steel dome in the world forms the roof of the West Baden Hotel, West Baden, Ind. Its span is 195 ft. c. to c. of pins. It is an aggregation of two-hinge arches, a drum at the center forming their common connection. The weight, including the steel framework and its covering is 475,000 lbs., or about 15 lbs. per sq. ft. of horizontal projection of roof surface.

Weight of Steel Arch Roof.—The Government building at the St. Louis Exhibition in 1904 contained steel roof trusses, which were three-hinged arches of 172 ft. span and 70 ft. rise. The trusses were spaced 35 ft. c. to c. The weight per square foot of horizontal projection was:

	Per sq. ft. Lbs.
Steel	13.1
Roofing	6.6
Tin covering	0.5
Total	20.2

Weight of Steel Fink Roof Trusses.—Mr. H. G. Tyrrell gives the following formula for the weight of steel roof trusses, based upon data of 146 separate trusses. The weight includes trusses complete, with rafter clips and shoe plates, but without ventilators.

$$W = \frac{S}{20} + \frac{12}{D}.$$

W = weight (lbs.) per sq. ft. of ground.
S = span in feet.
D = distance (in feet) c. to c.

Steel Frame, St. Louis Coliseum.—Mr. E. W. Stern gives the following relative to a coliseum built in 1897. The steel frame for the roof is an oblong dome, 186 x 298 ft. The 4 main trusses are three-hinged arches, 176 ft. span. There are 6 radial trusses at each end of the building. A traveler derrick, 63 ft. long, 31 ft. wide, and 42 ft. high, carried two derricks used to erect the trusses. The total weight of steel was 9,500 tons. There were 4,188 days' labor spent on the work in the shops, and 3,550 days' labor for erection, the average number of men in the erecting force being 50.

Each of the main arches weighed 64,000 lbs.; each radial arch, 21,000 lbs.

Materials in Large Grain Elevator.—A fireproof grain elevator, having a capacity of 3,100,000 bushels, was built in 1900 for the Great Northern Ry., at West Superior, Wis. It is 124 x 364 ft. in

plan and 246 ft. high. It has 505 steel bins. It rests on a pile and grillage foundation. The following are the quantities:

Foundation and Walls in Main Story:	
Piles, number	4,570
Timber and sheet piling, M	380
Excavation, cu. yds.	23,000
Masonry, cu. yds.	1,500
Concrete, cu. yds.	3,000
Cut stone, cu. ft.	1,300
Brick, cu. ft.	45,000
Superstructure:	
Structure below bins, tons	1,850
Bins proper, tons	6,500
Cupola, tons	1,450
Legs and spouts below bin floor, tons	450
Legs and spouts above bin floor, tons	350
Total steel, tons	10,600

There are 42 electric motors, having a total of 2,110 hp.

Cost of Fabricating and Erecting Steel Mill and Mine Buildings.— The following is a summary of data given in Ketchum's "Steel Mill Buildings," a book containing much excellent information on estimating steel work:

The drawings for steel mill buildings usually show only the dimensions of the "main members." The estimator usually calculates the weights of these main members and adds a percentage to provide for the weight of the "details." The "details" are the plates and rivets used in fastening the main members together. The weight of the "details" of trusses will commonly be 25 to 35% of the weight of the "main members," being usually nearer 25%. After computing the actual weights of details for a few buildings, the estimator will seldom blunder in computing by percentages.

In estimating the weight of corrugated steel, add 25% for laps where the side lap is two corrugations, and the end lap is 6 ins.; add 15% where the side lap is one corrugation and the end lap is 4 ins. Corrugated steel is usually made with corrugations 2½ ins. wide (from ridge to ridge) and ⅝-in. deep. The thickness of the steel is usually given in U. S. Standard Gage. The following are the weights per 100 sq. ft. of black corrugated steel:

Gage, No.	16	18	20	22	24	26	28
Lbs. per 100 sq. ft.	275	220	165	138	111	84	69

Add 16 lbs. per 100 sq. ft. if the steel is galvanized.

The cost of steel mill buildings is divided into four items: (1) cost of steel; (2) cost of shop work; (3) cost of transportation, and (4) cost of erection. The price of structural steel may be found in current numbers of "Iron Age," published in New York. The price is now (1905) about 1.8 cts. per lb. at New York.

The following are actual shop costs, in a shop having a capacity of 1,000 tons per month, and with labor estimated at 40 cts. per hr., which includes also the cost of management and the cost of operating and maintaining the shop equipment:

Cost of shop-work:

Columns, made of 2 channels and 2 plates, 1,000 lbs.....	0.8
Columns, made of single I-beam, or single angle..........	0.5
Columns, Z-bar..	0.8
Columns, plain, cast iron...............................	0.8 to 1.5
Riveted roof-trusses, 1,000 lbs. each..................	1.2
Riveted roof-trusses, 1,500 lbs. each..................	1.0
Riveted roof-trusses, 2,500 lbs. each..................	0.8
Riveted roof-trusses, 3,500 to 7,500 lbs. each............	0.6 to 0.75
Plate-girders, for crane girders and floors..............	0.6 to 1.3
Eye-bars, ¾ x 3 ins. x 16 to 30 ft......................	1.2 to 1.8
Eye-bars, large...	0.5 to 0.8
Steel frame transformer building, 60 x 90 ft., with 20-ft. posts, pitch of roof ⅓, 55,700 lbs. steel framework, including drafting..................................	1.0
Smelter building, 270 tons, including drafting.............	0.86
Six gallows frames, including drafting...................	1.0 to 2.0
Drafting design of "details" for .	
Ordinary buildings..................................	0.1 to 0.2
Headworks for mines................................	0.2 to 0.3
Roof-trusses	0.3 to 0.4

With skilled labor at $3.50 and common labor at $2 per 9-hr. day, the cost of erecting small buildings is about 0.5 ct. per lb., or $10 per ton, if trusses are riveted and other connections bolted.

The cost of erecting small buildings in which all connections are bolted is about 0.3 ct. per lb., or $6 per ton.

The cost of erecting heavy machine shops, all material riveted, is about 0.45 ct. per lb., or $9 per ton, including labor of painting.

The cost of erecting 6 gallows frames was 0.65 ct. per lb., or $13 per ton.

The cost of laying corrugated steel roof is about $0.75 per square, or $9 per ton for No. 20 steel, when laid on plank sheathing; it is $1.25 per square, or $15 per ton, when laid directly on the purlins; it is $2 per square, or $24 per ton, when laid with anti-condensation roofing. The erection of corrugated steel siding costs $0.75 to $1.00 per square, or $9 to $12 per ton for No. 20 steel.

Cost of Erecting the Steel in Buildings.—The costs are given in tons of 2,000 lbs. On a four-story, fireproof hospital the cost of erecting the steel and cast iron was $4.50 per ton; hand derricks were used, and the work was all done by common laborers, at $1.50 per day. With a steam derrick the cost might have been reduced to $3.50 per ton. On a three-story business block, under the same conditions as before, the store fronts were erected for $5 per ton.

On a large railroad machine shop, with structural steel workers at 40 cts. per hr., the cost of erecting was $8 per ton. In this case the work was all heavy, the lightest truss weighing 5 tons. On train sheds, and where lighter sections were used, and where there were more field rivets to the ton, the cost was $10. Ordinarily there are about 10 field rivets to the ton, and it is safe to allow 10 cts. each, or $1 per ton for riveting alone. There are buildings in which 25 field rivets per ton are required. The foregoing costs of steel erection include unloading from cars, setting derricks and scaffolding.

The cost of erecting large electric cranes is about $3 per ton if put in place directly from the cars. Add $1.50 per ton if unloaded from cars before erecting.

The steel frames of modern office buildings are usually erected by derricks high enough to erect two or three floors without shifting. The cost of erecting and riveting the steel is $10 to $15 per ton. The trusses of small roofs can be erected cheaply by the use of one or two gin poles.

Area of Passenger Stations.—In the Proc. Am. Ry. Eng. and Mn. of Way Assoc., 1904, a committee report gives the average area of passenger stations for cities of 10,000 to 15,000 population on 31 different railways, as follows:

	Sq. ft.
Waiting rooms	1,160
Toilet rooms	186
Baggage rooms	433
Ticket offices	218
Total	1,997

Such a station would measure about 24 x 84 ft. inside.

Cost of Moving a Frame Dwelling House.*—This building was moved at Secaucus, N. J., during the month of July, 1906, under contract, to make room for freight yard extensions. The house (weighing about 50 tons) was 30 ft. square, two stories in height, with a one-story extension in the rear 12 x 18 ft., all resting upon brick piers standing 2 ft. above level of ground. The building was first raised about 14 ins. with jack screws and blocking. Several long 12-in. x 12-in. timbers were then placed under the joists lengthwise and crosswise, all properly cleated and fastened, care being taken to support the two chimneys. The movement was accomplished with windlass, team, driver and about 1,000 ft. of 2-in. manilla rope passed through the blocks, the building sliding forward upon greased supports of way of long timbers blocked up to the proper height. It was moved forward a distance of 115 ft., then turned about 90° and pulled backward a distance of 435 ft. to its new location, making a total distance traveled of 548 ft.

During the moving the force was kept busy greasing timbers with soap and carrying blocking forward. At intervals the moving was stopped, the team detached from the windlass and used to haul the long timbers ahead. In moving it was necessary to cross over two roads and pass under three lines of light and telephone wires. Men were stationed upon the top of the house to lift the wires over the roof and chimneys. Previous to moving, the building was strengthened to prevent racking, by placing several temporary bents in rooms on first floor. The only damage occurred from plaster cracking around chimneys, and this was slight. The tenants occupied the house during the moving period.

Wages for laborers were $2.00 per day, hours from 7 a. m. to 6 p. m., and half days on Saturday, for which they received a full day's pay. The foreman received $3.50 per day, utility man $3.00 per day, night watchman $2.00 per day. Teams were paid at the

*_Engineering-Contracting_, Oct. 30, 1907.

rate of $1.50 per day and 75 cts. per day was paid for a horse. During the moving drivers worked as laborers.

The actual labor cost is divided as follows:

		Per cent.
Hauling blocking, lumber and tools (9 miles for round trip)	$ 27.00	9.1
Placing and removing blocking timbers, raising and lowering before and after moving	102.00	34.5
Moving building (548 ft.)	166.75	56.4
Total moving	$295.75	100.0

The time occupied in doing the work including the time lost for Sundays, holidays and rain was 24 days. Actual number of days worked was 16. The total cost of this moving to contractor was $357.50, the extra $61.75 (added to $295.75) being wages paid to foreman, 2 drivers and watchman for Sundays, holidays and days lost on account of rain.

For the above information we are indebted to Mr. A. L. Moorehead, C. E.

References.—Any one engaged in estimating the cost of very many buildings will do well to consult Arthur's "Building Estimator," Tyrrell's "Mill Buildings," Ketchum's "Steel Mill Buildings," and Kidder's "Architects' and Builders' Pocket Book."

The prices of hardware may be obtained from "The Iron Age Standard Hardware List" ($1), published by The Iron Age, New York City. The current discounts are given in The Iron Age, a copy of which costs 10 cts.

The prices of lumber are quoted weekly in such papers as the "New York Lumber Trade Journal." Different mills issue catalogs giving prices of mill work.

SECTION XI.

RAILWAYS.

Cross-References on Cost of Grading.—The reader is referred to the Earth Excavation and Embankment Section, and to the Rock Excavation Section, for costs of grading. The cost of tunneling is given on page 1180, etc.

Cross-References on Bridges, Culverts and Buildings.—For data on these subjects, consult the "Bridges and Culvert Section," the "Timberwork Section," and the "Building Section," of this book. Use the index for the item in question.

Cost of Transporting Men, Tools and Supplies on Railroads for Grading.*—In carrying on construction work it is the custom of railroads to charge to construction certain rates of fares on the men employed, and freight on tools and supplies. This charge against the new work is credited to the operating department. Engineers in the employ of a railroad company in making up estimates for new work must include these charges, else the cost of the work is likely to overrun the estimate. To do tnis there must be some basis of the amount of work that a man, horse and machine will do in a given time, and an approximate tonnage of machines and supplies needed to excavate a given unit.

The same assumption applies to track work, bridges and buildings, but in this article we consider only the grading of a railroad.

The following figures have been used by one of the editors of this journal in estimating the cost of railroad construction. The figures of work done, and men, horses and tools and supplies needed are based on large jobs of construction, and are safe averages. The fares for men and the freight rates are those ordinarily charged by railroads for such movement of men and freight.

The costs follow:

One horse plus 1½ men readily excavate and move 15 cu. yds. of earth per day. Hence allow 360 cu. yds. per month per horse and 250 cu. yds. per month per man.

One man requ'res transportation at 1 ct. per mile, and freight on 200 lbs. of bedding, cooking utensils, tents, small tools, etc.

**Engineering-Contracting*, July 8, 1908.

Hence for 100 miles transportation each way, or 200 miles round trip, we have

200 passenger miles at 1 ct.	$2.00
1/10 ton bedding, etc., 200 miles at ½ ct. per ton mile	.10
Total	$2.10

Since one man will excavate 250 cu. yds. per month, it costs $2.10 divided by 250, or 0.8 ct. per cu. yd., if the job lasts only one month; but if the job lasts four months it costs 0.8 ct. divided by 4, or 0.2 ct. per cu. yd., because in that time a man will move 4 times 250 cu. yds., or 1,000 cu. yds., and will only require transportation once at a cost of $2.10. Other months are in proportion. For any other haul than 100 miles multiply accordingly.

Each horse requires the following equipment:

	Lbs.
½ wheel scraper, at 500 lbs.	250
½ wagon, at 2,000 lbs.	1,000
Tents, harness, etc.	250
Total	1,500

Allowing 16 horses per car of 24,000 lbs., each horse stands for freight equivalent to 1,500 lbs, hence:

	Lbs.
Equipment for each horse	1,500
Weight of horse	1,500
Total, 1½ tons or	3,000

For each 100 miles of haul we have, therefore, 200 miles round trip; hence 200 miles × 1½ tons × 0.4 ct. = $1.20.

Since each horse moves 360 cu. yds. per month, we have $1.20 ÷ 360, or 0.3 ct. per cu. yd., if the job lasts only one month. But if the job lasts four months we have ¼ of 0.3 ct., or 0.075 ct. per cu. yd. Other lengths of time and other hauls are in proportion.

Each horse consumes ½ ton of food per month; hence if food is hauled 100 miles we have ½ ton × 100 miles × 0.4 ct. = 20 cts.

Since the horse moves 360 cu. yds. per month, we have 20 cts. ÷ 360, or 0.05 ct. per cu. yd. for each 100 miles of haul.

Summing up, we have the following costs:

	Cost per cu yd. for transportation 100 miles and return.			
Duration of work.	Men. Cts.	Horses. Cts.	Food. Cts.	Total. Cts.
1 mo.	0.80	0.30	0.05	1.15
4 mos.	0.20	0.08	0.05	0.33
6 mos.	0.13	0.05	0.05	0.23
8 mos.	0.10	0.04	0.05	0.19
12 mos.	0.07	0.03	0.05	0.15

Note.—If the haul is 300 miles, multiply by 3. If the haul is 500 miles, multiply by 5. If the haul is 1,000 miles, multiply by 10.

The above is for work done by wheel scrapers and wagons and carts, but for steam shovel work the following would be the approximate cost for transportation:

	Tons.
1 shovel	70
60 dump cars	120
Rail	65
Cross ties (6"x6"x6')	75
Three small locomotives	35
Pumps, drills, etc.	35
Total	400

400 tons × 100 miles × 0.4 ct. = $160.

Such a shovel as this will average at least 20,000 cu. yds. per month, hence we have $160 ÷ 20,000, or 0.8 ct. per cu. yd. for transporting the shovel 100 miles. This is equivalent to 1.6 cts. for transporting the shovel the round trip of 200 miles, when the job lasts only one month. For four months the cost would be ¼ of 1.6 cts., or 0.4 ct. per cu. yd. Other months would be correspondingly in proportion.

Such a shovel does not consume more than 60 tons of fuel and supplies per month; hence we have 60 tons × 100 miles × 0.4 ct. = $24. Since with this 60 tons of fuel there are 20,000 cu. yds. excavated, we have $24 ÷ 20,000, or 0.12 ct. per cu. yd. With such a shovel there will never be more than 40 men engaged in operating the shovel, operating the dump cars and trains, as well as in making temporary roadways and repairing equipment; hence each of these 40 men averages 500 cu. yds. per month, which is double the output where men are working with wheel scrapers, carts, etc., as above given; therefore the cost of transporting men per cu. yd. on shovel work is approximately one-half the amount given in the previous table.

Summing up we have the following:

	Cost per cu yd. for transportation 100 miles and return.			
	Shovel.	Men.	Fuel.	Total.
Duration of work.	Cts.	Cts.	Cts.	Cts.
1 mo.	1.60	0.40	0.12	2.12
4 mos.	0.40	0.10	0.12	0.62
6 mos.	0.26	0.07	0.12	0.45
12 mos.	0.13	0.03	0.12	0.28

The above is for a haul of 100 miles, and for any other hauls multiply according to the length of haul.

If the workmen are of a restless disposition, and remain only a month or two on the job before quitting, the cost of their transportation varies not with the length of the job but with the average time they remain on it. When they quit of course their return fare is not paid.

Cost of Three Short Single-Track Tunnels.*—Short tunnels are usually constructed at less cost than long tunnels, not only because of the less cost of hauling and "muck" and the ease of ventilating the tunnel, but because a very inexpensive plant can be used. In limestone and sandstone formations the present contract prices average about

---

**Engineering-Contracting*, Aug. 21, 1907.

$45 per lin. ft. of single-track tunnel for all lengths up to 1,000 ft. or so, even where common laborers receive $2.25 a day. The following data give the cost (at contract prices) of three tunnels built in the West, and, both as to prices and as to quantities, these examples will be useful to engineers and contractors:

TUNNEL NO. 1 (900 LIN. FT.).

	Per lin. ft.
Excavating tunnel	$45.00
2.7 cu. yds. enlargement for lining, at $3.00	8.10
350 ft. B. M. timber lining, at $20	7.00
5.7 lbs. iron, at $0.03	0.17
Total	$60.27

TUNNEL NO. 2 (600 LIN. FT.).

	Per lin. ft.
Excavating tunnel	$45.00
2.7 cu. yds. enlargement, at $3.00	8.10
370 ft. B. M. lining, at $20.00	7.40
5.5 lbs. iron, at $0.03	0.17
Total	$60.67

TUNNEL NO. 3 (400 LIN. FT.).

	Per lin. ft.
Excavating tunnel	$42.50
2.8 cu. yds. enlargement, at $3.00	8.40
400 ft. B. M. lining, at $20.00	8.00
7.4 lbs. iron at $0.03	0.22
Total	$59.12

In addition to the above costs which are based on the contractor's final estimate, there was a cost of $3 per lin. ft. (or about 5%) for engineering and superintendence, and a cost of $0.50 per lin. ft. for train service.

Cost of the Stampede Tunnel.*—Mr. Charles W. Hobart gives the following data on the Stampede or Cascade Tunnel of the Northern Pacific R. R. Bids were opened in New York Jan. 21, 1886, for a single-track tunnel, 9,844 ft. long, to be completed in 28 mos. Of the 12 bids, that of Mr. Nelson Bennett was lowest and was accepted. A forfeit of $100,000 and 10% of the contract price for failure to complete within the time was required. Mr. Bennett telegraphed his general manager to gather men and clear a road to get the machinery on the ground. The plant was purchased for $100.000 in New York and shipped. It consisted of 5 engines, 2 water wheels, 5 air compressors, 5 boilers of 70-hp. each, 4 fans, 2 electric arc light plants, 2 miles of 6-in. wrought iron, 2 miles of water pipe, 2 machine shop outfits, 36 air drills, 2 locomotives, 60 dump cars, 2 saw mills and other necessaries. This plant had to be transported on wagons and sleds from Yakima, Wash., a distance of 82 miles to the east portal of the tunnel and 87 miles to the west portal. The first wagon loads started Feb. 1, and the first boiler

*Gillette's "Rock Excavation."

Feb. 22. By June 19 the plant for the east portal, and by July 15 the plant for the west portal had reached its destination. On Feb. 13 hand drilling was begun on the east portal and 411 ft. of tunnel had been driven when the machines began June 19. On March 15 hand drilling started at the west end and by Sept. 1, when the machines started, 488 ft. had been driven. The last 15 miles of the hauling before reaching the mountains was in mud, so that wagons were hauled by block and tackle, planks being laid down in front of the wheels and taken up as fast as the wagons passed. About one mile a day was covered in this way. When the mountains were reached sleds were improvised and hauled by block and tackle with teams. Wagons lightly loaded with provisions traveled 12 miles a day.

The cost of clearing the way and getting the machinery and materials on the work was $125,000,* and 6 mos. time was required. The tunnel was to be 9,950 ft. long, 16½ x 22 ft. in the clear; 900 ft. had been driven by hand, leaving 9,050 ft. to be driven in 22 mos.

An 8-ft. heading was driven along the top of the tunnel and was kept 30 ft. ahead of the bench. The tunnel was timbered as work progressed. The average number of men employed, after the machinery was installed, was 350. They worked 10-hr. shifts, receiving $2.50 to $5 a day. Contractor boarded men at 75 cts. a day. A bonus of 25 cts. a day was paid each laborer for every foot gained during the month over the necessary average of 13.6 ft. a day in both headings combined, and each driller received a bonus of 50 cts. per day per ft. gained. Every day of the year was worked, requiring two shifts of 75 men each, beside the engineers, firemen, carpenters, machinists, etc., making a monthly payroll of $30,000. The best month's progress was April, 1888, when a total advance of 540 ft. was made in the two headings, or 9 ft. a day per heading. The average progress for 21⅝ mos., with power drills, was 413 ft. per month for the two headings. On May 3, 1888, the headings met, and on May 14 the excavation was completed, 7 days before the time limit. The track was laid in two days more and on May 22 the first regular train passed through the tunnel.

The total explosives used were 309,625 lbs., as follows:

	No. of 50 lb. boxes.
Giant No. 1, 60 per cent	408¾
Giant No. 2, 45 per cent	2,123½
Hercules No. 1, 60 per cent	1,609½
Hercules No. 2, 45 per cent	1,781¾
Nitro glycerin No. 2	232
Forcite No. 2	41½
Total No. of 50-lb. boxes	6,192

The average price of all explosives was $10 a box, or 20 cts. per lb. The total number of men killed in the two years was 13. The following data were furnished by Mr. Andrew Gibson, Assistant Engineer. The American center-cut system of blasting was used;

*Wages were $2.50 for laborers, which is a high price.

20 to 23 holes, 12 ft. deep, being drilled in the heading, and about 18 holes in the bench. Each drill, in medium hard rock, would make 6 or 7 holes in 5 hrs., although at times in an exceedingly hard layer 15 hrs. would be required. About 400 lbs. of dynamite were used at each blast in each of the headings and benches. This would break 8 to 12 lin. ft. of tunnel, although in very hard rock at times only half this progress was made. The rock is basaltic,* with a dip of 5° to the west. It required immediate timbering, which delayed the drillers and muckers about 25% of the time. During the period of hand drilling there were 17 men, with about 23 muckers, employed in each heading, and 4 lin. ft. of tunnel in 24 hrs. were averaged. During the period of air drilling, 10 drills were used, 5 in each end, and the progress was 6.9 ft. in 24 hrs. per heading, or 207 ft. per mo. of 30 days. While the contract size of the tunnel was 16½ ft. wire, and 22 ft. from subgrade to face of arch, the timbered sections had to be excavated 19½ ft. wide by 24 ft. high, thus requiring 15.7 cu. yds. of excavation per lin. ft. where timbering was used, as against 12.36 cu. yds. where no timber was used. Timbers were 12 x 12 ins., except the 8 x 12-in. sills. Five segments were used in the arch, lagged with 4 x 6-in. pieces. Bents were spaced 2 to 4 ft. Water gave no trouble.

Mules were used for hauling up to the first half mile; then small locomotives, which hauled 8 to 12 cars. A "go-devil" or platform on wheels was used to great advantage in loading cars. The men wheeled the rock on plank runways from the heading to the "go-devil," dumping directly into cars below; and the muckers on the heading never interfered with those on the bench. It was also a great convenience in timbering. Before blasting the drills were loaded upon the "go-devil," and it was pushed back some distance from the face. Endless belt conveyors for removing muck to the "go-devil" were contemplated, but they were never used, as with the large force of men at work they would have been in the way.

The swelling of the shale on exposure often reduced a 12-in. timber to 4 ins.; hence it was necessary to line the tunnel with masonry. Concrete side walls and a brick arch were used for lining. The concrete mortar was brought in on cars and run back of the forms through spouts, without shoveling; then the broken rock was shoveled into the mortar from a flat car.

The total cost of the tunnel to the N. P. R. R. under Mr. Bennett's contract (which did not include masonry lining) was $118 per lin. ft. Mr. Bennett's brother was the superintendent of the work. The actual cost of tunnelling the west end during the month of November, 1887, was $75.75 per ft. for the 258 ft. driven, distributed as follows:

*Elsewhere it is stated that the rock was shale.

Labor.

Superintendent, ½ mo., at $500............$	250.00
Superintendent, 1 mo., at $250............	250.00
Master mechanic, ½ mo., at $150..........	75.00
Engineers, 4 x 30 = 120 days, at $4........	480.00
Machine repairers, 3 x 30 = 90 days, at $3.50	315.00
Firemen, 4 x 30 = 120 days, at $2.50........	300.00
Blacksmiths, 2 x 30 = 60 days, at $4.00.....	240.00
Blacksmiths helpers, 2 x 30 = 60 days, at $2.50	150.00
Carpenters, 396 days, at $3.00.............	1,188.00
Foremen, 160 days, at $4.50...............	720.00
Drillmen, 294 days, at $3.50...............	1,029.00
Chuckmen, 293 days, at $3.00..............	879.00
Muckers, 1,138 days, at $2.75..............	3,129.50
Nippers, 60 days, at $2.50.................	150.00
Dumpmen, 60 days, at $2.50...............	150.00
Car drivers, 60 days, at $2.50.............	150.00
Timekeeper, 30 days, at $2.50..............	75.00
Lampmen, 60 days, at $2.50...............	150.00
Laborers, 662 days, at $2.50..............	1,655.00
Bonus for daily progress over 6 ft..........	500.00
Total labor for 258 ft., at $45.90 per ft....$	11,835.50

Material.

78,000 ft. B. M. timber, at $10.............$	780.00
800 lbs. wrt. iron, at 6 cts.................	48.00
64½ cords wood, at $3....................	193.50
240 tons coal, at $4......................	960.00
900 caps, at 1 ct..........................	9.00
14,400 ft. fuse, at 1 ct....................	144.00
13,800 lbs. dynamite, at 16 cts.............	2,208.00
Total materials for 258 ft., at $16.80 per ft.$	4,342.50

Plant.

6 per cent of $50,000 plant, 1 mo...........$	250.00
1/28 of 75 p. c. depreciation * of $50,000 plant	1,339,28
10 p. c. on all above to cover all possible omissions	†1,776.72
Total plant charges for 258 ft., at $13.05..$	3,366.00

*Note that a liberal but not unusual allowance is made for plant depreciation.

†This 10 per cent, practically covers the cost of installing the plant.

Summary of cost per ft.

Labor	$45.90
Material	16.80
Plant	13.05
Total	$75.75

During this month the entire length was lined with timber, the rock being a soft basaltic rock that drills well but goes to pieces rapidly on exposure. There were no accidents or delays.

On the east end during this same month, with an equal force, the progress was 246 ft., at a cost of $72.70 per ft. It will be noted that wages were high. It will also be noted that the cost of hauling and installing the plant is not included, although a liberal allowance is made for plant depreciation and in the 10% added to cover omissions.

The contractor received for his month's work on the west end of the tunnel:

258-ft. tunnel, standard sections, at $78.......	$20,124
862 cu. yds. extra excav., at $4.50.............	3,879
78,000 ft. B. M. lining, at $35................	2,730
258 ft. of tunnel, timbered, at $103.62.......	$26,733

The best month's record in driving a heading was 274 ft. but, as before stated, the average progress with the air drills was 207 ft. per mo. per heading, although in the month of November, 1887, 258 ft. were progressed on the west end, which was 25% better than the average progress. Assuming that 15.7 cu. yds. were excavated per lin. ft. of tunnel, the total excavation at the west end for November was 4,052 cu. yds. It is probable that the 862 cu. yds. extra excavation, above given, are included in this estimate, because the "standard section" differed from the timbered section by 3.3 cu. yds. per lin. ft., and in 258 ft. this would amount to 852 cu. yds. On this assumption (of 4,052 cu. yds.) the labor cost $2.92 per cu. yd.; the materials, $1.07 per cu. yd.; and the plant, $0.83 per cu. yd.; total, $4.82 per cu. yd. for the best month's work.

Further data on this tunnel are given in the following paragraphs.

Cost of the Stampede Tunnel and Its Masonry Lining.*—The Stampede Tunnel on the Northern Pacific Ry. is 9,844 ft. long and was built in 1886 to 1888 by contract. The contract work included the excavation of this tunnel and the timber lining. Subsequently this timber lining was replaced with a masonry lining by the railway company's own forces. This article gives in detail the cost of the permanent masonry lining. To make the cost figures complete, however, we itemize the contract costs of the original construction as follows:

	Per lin. ft.
Excavation, standard section, at $78..........	$ 78.00
Extra excavation, 3.2 cu. yds., at $4.50........	14.40
Timber lining, 305 ft. B. M., at $35...........	10.68
Traffic charges............................	0.77
Total	$103.85
Ballast	0.90
Track materials...........................	1.23
Track laying.............................	0.18
Track surfacing..........................	0.16
Engineering	5.00
Total	$111.32

The above figures are the contract costs to the Northern Pacific Ry.

*Engineering-Contracting, June 3, 1908.

The permanent masonry lining work, whose cost is given here, was begun June 16, 1889, and completed Nov. 16, 1895, the progress in lineal feet per year being as follows:

	Walls.	Arch.
1889	1,176	.....
1890	1,280	538
1891	2,549	871
1892	5,038	1,402
1893	2,930	911
1894	3,229	2,812
1895	2,301	2,887

The side walls were of concrete and the arch was of brick, there being 30,259 cu. yds. of concrete side walls and 18,426 cu. yds. of brick arch, or a total of 48,683 cu. yds. of masonry lining in the 9,311 lin. ft. that were lined. There were, therefore, 3¼ cu. yds. of concrete side walls and 2 cu. yds. of brick arch, or a total of 5¼ cu. yds. per lin. ft. of tunnel.

The average cost of the lining was as follows:

Concrete Side Walls:	Per cu. yd.	Per lin. ft.
Cement, at $2.90 per bbl.	$4.27	$13.95
Rock, at 31 cts. per cu. yd.	0.24	0.80
Sand, at 21 cts. per cu. yd.	0.12	0.40
Traffic charges	0.35	1.13
Train service	0.96	3.12
Labor	2.10	6.87
False work	0.08	0.27
Tools, lights, etc.	0.10	0.33
Engineering and superintendence	0.16	0.53
Total	$8.38	$27.40

Brick Arch:	Per cu. yd.	Per lin. ft.
Cement, at $2.90 per bbl.	$ 2.93	$ 5.80
Brick, at $7.12 per M.	3.56	7.04
Rock backing, at 59 cts. per cu. yd.	0.41	0.81
Sand, at 40 cts. per cu. yd.	0.14	0.27
Traffic charges	0.36	0.71
Train service	1.21	2.39
Labor	4.20	8.32
Falsework	0.22	0.43
Tools, lights, etc.	0.21	0.41
Engineering and superintendence	0.25	0.50
Total	$13.49	$26.68

Since the concrete side walls cost $27.40 per lin ft. and the brick arch cost $26.68, the total cost was $54 per lin. ft. of tunnel, which, if added to the $111 above given, makes a grand total of $165 per lin. ft. Had the masonry lining been built in the first place, the cost would have been considerably less.

The item of "traffic charges" covers freight on materials at 1 ct. per ton-mile. The item of "train service" covers hauling of sand, rock, etc., with a work train.

The cost of this lining was very much higher during the first years of the work. This was due partly to the greater thickness of the lining used at first, but it was principally due to the inexperi-

ence of the men and the higher cost of materials. The following table shows the cost by six-month periods:

6 mos. ending.	—Brick Arch.— Lin. ft.	Cost per lin. ft.	—Concrete Wall.— Lin. ft.	Cost per lin. ft.	Total per lin. ft.
June 30, 1889....	...	.....	33	$61.72	.....
Dec. 31, 1890....	...	.....	1,143	61.72	.....
June 30, 1890....	257	63.24	....	....	$124.96
Dec. 31, 1890....	281	63.24	1,280	56.92	120.16
June 30, 1891....	600	51.64	733	40.94	92.58
Dec. 31, 1891....	271	51.64	1,816	40.94	92.58
June 30, 1892....	517	34.90	2,422	22.06	56.96
Dec. 31, 1892....	885	27.13	2,616	19.80	46.93
June 30, 1893....	496	25.35	2,219	19.48	44.83
Dec. 31, 1893....	415	20.96	711	19.40	40.36
June 30, 1894....	904	20.21	3,229	16.55	36.76
Dec. 31, 1894....	1,898	19.40	.....	.....	.....
June 30, 1895....	1,225	18.90	2,187	18.04	36.94
Dec. 31, 1895....	...	.....	114	.....	.....
Total	9.311		18,503		

The foregoing shows the progressive decrease in the cost per lineal foot. The following table shows the decrease in the cost per cubic yard:

Six mos. ending.	Brick Arch. Cu. yds.	Cost per cu. yd.	Concrete Walls. Cu. yds.	Cost per cu. yd.
June 30, 1889..........	...	.....	83	$12.26
Dec. 31, 1889..........	...	.....	2,876	12.26
June 30, 1890..........	617	$26.35	.....	.....
Dec. 31, 1890..........	674	26.35	3,224	11.30
June 30, 1891..........	1,740	17.90	1,303	11.51
Dec. 31, 1891..........	786	17.90	3,228	11.51
June 30, 1892..........	1,092	16.53	3,582	7.33
Dec. 31, 1892..........	1,634	14.69	3,488	7.42
June 30, 1893..........	916	13.72	2,951	7.32
Dec. 31, 1893..........	751	11.58	1,139	6.05
June 30, 1894..........	1,645	11.10	4,720	5.66
Dec. 31, 1894..........	3,479	10.55	.....	.....
June 30, 1895..........	2,322	10.21	3,495	5.64
Dec. 31, 1895..........	2,770	.....	170	.....
Total and av.......	18,426	$13.49	30,259	$ 8.38

The cost of lining the tunnel during the six months ending Dec. 31, 1892, represents about an average of the whole job. It was as follows:

CONCRETE SIDE WALLS.

Materials:	Per cu. yd.
Cement, 1.5 bbls., at $2.36	$3.54
Sand, 0.33 cu. yd., at 36 cts.	0.12
Rock, 0.5 cu. yd., at 55 cts.	0.28
Dry rock backing, 0.04 cu. yd., at 55 cts.	0.02
Total	$3.96
Traffic Charges:	
Cement	$0.24
Sand	0.17
Rock	0.18
Total	$0.59

Work Train Service:

Hauling concrete, removing old timbers and excavating material, 0.031 day of work train, at $26.90	$0.83
Labor:	
Mixing cement dry, 0.104 day, at $2.50	$0.26
Building walls, 0.247 day, at $2.84	0.70
Removing timbers, excavating and preparing panel for concrete, 0.226 day, at $2.83	0.64
Placing rock backing, 0.02 day, at $2.50	0.05
Total	$1.65
Engineering, Superintendence and Miscellaneous:	
Engineering	$0.29
Falsework, timber and iron	0.06
Lights, wear on tools, etc.	0.03
Interest and depreciation of plant, 10% per annum on $1,500, for 3½ mos.	0.01
Total	$0.39
Total per cu. yd. in place	$7.42

The proportions were 1 cement, 3 sand and 5 rock. The dimensions of each side wall were 2 ft. 3 ins. thick and 16 ft. high. There were 1.33 cu. yds. of concrete per lin. ft. of side wall, or 2.66 cu. yds. per lin. ft. of tunnel. The average daily force, not including the work train crew, was:

1 foreman, at $135 per mo.
1 foreman, at $3.75 per day.
1 foreman, at $3.25.
3 carpenters, at $3.
22 laborers, at $2.50.
4 laborers, at $2.

The average daily progress was 38.75 cu. yds. per day.

The average daily force "building the side walls" was:

1 foreman, at $135 per mo.
2 foremen, at $3.25 per day.
4 carpenters, at $3.
12 laborers, at $2.50.

The average daily force engaged in "removing timbers, excavating, etc.":

1 foreman, at $135 per mo.
2 foremen, at $3.75 per day.
2 carpenters, at $3 per day.
14 laborers, at $2.50 per day.

The cost of the brick arch during the same period was:

BRICK ARCH.

Materials:	Per cu. yd.
Brick, 526, at $7 per M	$ 3.68
Cement, 1.18 bbls., at $2.40	2.83
Sand, 0.263 cu. yd., at 82 cts.	0.21
Dry rock backing, 0.483 cu. yd., at 75 cts.	0.36
Total materials	$ 7.08

Traffic Charges:

Brick	$ 0.89
Cement	0.19
Sand	0.13
Total	$ 1.21

Work Train Service:

Hauling brick and cement and removing debris and old timber, 0.046 day, at $26.70	$ 1.23

Labor:

Mixing mortar and building arch, 0.78 day, at $4.06	$ 3.16
Placing rock, backing, 0.135 day, at $2.66	0.36
Moving centers, preparing for work and removing timber 0.383 day, at $2.87	1.10
Total	$ 4.62

Engineering, Superintendence and Miscellaneous:

Engineering and superintendence	$ 0.44
Falsework, timber and iron	0.05
Changing lights, wear on tools, etc.	0.04
Interest and depreciation of plant, 10% per annum on $1,500, for 2½ mos.	0.02
Total	$ 0.55
Total per cu. yd.	$14.69

The brick arch was 5 rings thick, or 1 ft. 9 ins., and 28½ ft. around the arc. The bricks were 2⅛ x 3⅞ x 8 ins. There were 1.85 cu. yds. of brick masonry per lin. ft. of tunnel, making the cost $27.13 per lin. ft. for the brick arch. The average daily progress was 25.9 cu. yds., with the following force, not including work train crew:

1 foreman, at $135 per mo.
1 brick mason foreman, at $6.50 per day.
1 foreman, at $3.75 per day.
1 foreman, at $3.25 per day.
7 brick masons, at $6 per day.
3 carpenters, at $3 per day.
25 laborers, at $2.50 per day.

The average gang engaged in "mixing mortar and building arch" was:

1 foreman, at $135 per mo.
1 foreman, at $3.75 per day.
2 brick foremen, at $6.50 per day.
7½ brick masons, at $6 per day.
1 carpenter, at $3 per day.
21 laborers, at $2.50 per day.

The average gang engaged in "placing rock backing" was:

1 foreman, at $135 per mo.
2 foremen, at $3.25 per day.
4 carpenters, at $3 per day.
30 laborers, at $2.50 per day.

The average gang engaged in "removing timbers, excavation, etc.," was:

1 foreman, at $135 per mo.
2 foremen, at $3.75 per day.
5 carpenters, at $3 per day.
12 laborers, at $2.50 per day.

As above stated, the cost during the last year of the work was very much reduced.

During the six months ending June 30, 1895, the cost of lining was as follows:

CONCRETE SIDE WALLS.

Materials:	Per cu. yd.
Cement, 1.33 bbls., at $2.25	$2.99
Sand, 0.47 cu. yd., at 18 cts.	0.09
Rock, 0.79 cu. yd., at 39 cts.	0.31
Total	$3.39
Work Train Service:	
Hauling concrete, removing debris and old timber, 0.022 day, at $22.90	$0.51
Labor:	
Mixing cement, 0.07 day, at $2.14	$0.
Building walls, 0.28 day, at $2.40	0.66
Removing timbers, excavating and preparing panel for concrete, 0.21 day, at $2.62	0.54
Total	$1.35
Engineering and Miscellaneous:	
Engineering and superintendence	$0.22
Falsework, timber and iron	0.06
Tools, lights, etc.	0.10
Interest and depreciation of plant, 10% per annum of $1,500, for 3 mos.	0.01
Total	$0.39
Total per cu. yd.	$5.64

It will be noted that "traffic charges" (freight on the materials for concrete) appear to have been omitted.

The proportions of the concrete were 1:3:5. The side wall was 2 ft. 7 ins. thick by 16 ft. high, and each side wall contained 1.6 cu. yds. per lin. ft. The average progress per day was 46 cu. yds., and the working force was as follows:

1 foreman, at $112.50 per mo.
1 foreman, at $90 per mo.
1 foreman, at $3.50 per day.
1 blacksmith, at $3 per day.
2 carpenters, at $3 per day.
19 laborers, at $2.25 per day.
7 laborers, at $1.75 per day.

The cost of the brick arch during the same period was as follows:

BRICK ARCH.

Material.	Per cu. yd.
Brick, 500, at $6.35	$ 3.18
Cement, 0.98 bbl., at $2.25	2.21
Sand, 0.34 cu. yd., at 28 cts.	0.09
Total	$ 5.48
Work Train Service:	
Hauling material, debris, etc., 0.037 day, at $24.25	$ 0.91
Labor:	
Mixing mortar and building arch, 0.57 day, at $3.15	$ 1.80
Placing rock backing, 0.09 day, at $2.29	0.21
Removing old timbers, excavating and preparing for arching and moving centers, 0.32 day, at $2.48	0.80
Total	$ 2.81
Engineering and Miscellaneous:	
Engineering and superintendence	$ 0.23
Falsework, timber and iron	0.09
Tools, lights, etc.	0.20
Interest and depreciation of plant, 10% per annum on $1,500, for 3 mos.	0.02
Total	$ 0.54
Total per cu. yd.	$10.21

It will be noted that the item of "traffic charges" appears to have been omitted.

There were 5 rings of brick in the arch, giving a thickness of 1 ft. 9 ins., and the length of the arc was 28 ft. There were 1.85 cu. yds. of brick masonry per lin. ft. of tunnel. The bricks were 2⅛ x 3⅞ x 8 ins.

The average progress per day was 44.2 cu. yds. with the following force:

1 foreman, at $112.50 per mo.
1 foreman, at $90 per mo.
1 foreman, at $3.50 per day.
1 brick mason foreman, at $5.50 per day.
8 brick masons, at $5 per day.
1 carpenter, at $3 per day.
1 blacksmith, at $3 per day.
27 laborers, at $2.25 per day.

The gang when engaged in "mixing mortar and building arch" was as follows:

1 foreman, at $112.50 per mo.
2 foremen, at $3.50 per day.
2 mason foremen, at $5.50 per day.
1 timekeeper, at $60 per mo.
17 brick masons, at $5 per day.
1 blacksmith, at $3 per day.
25 laborers, at $2.25 per day.

The gang when engaged in "placing rock backing" was as follows:

1 foreman, at $112.50 per mo.
⅓ timekeeper, at $60 per mo.
⅓ blacksmith, at $3 per day.
¼ carpenter, at $3 per day.
22 laborers, at $2.25 per day.

The gang when engaged in "removing old timbers, etc.," was as follows:

1 foreman, at $112.50 per mo.
3 foremen, at $90 per mo.
1 timekeeper, at $60 per mo.
3 blacksmiths, at $3 per day.
1 carpenter, at $3 per day.
17 laborers, at $2.25 per day.

Cost of the Cascade Tunnel.—The tunnel is 13,813 ft. long through the Cascade Mountains on the line of the Great Northern Ry. The width in the clear is 16 ft., and the height from top of rail to bottom of arch is 21½ ft. It was begun, from two headings, Aug. 20, 1897, and completed Oct. 13, 1900. A top heading, 10 x 20 ft., was driven from each end; and the bench was taken out in two lifts. The average monthly progress was 175 ft. at each heading, or 5.76 ft. per day of 24 hrs. The best year's work was from June 1, 1899, to June 1, 1900, in which time 5,575 ft. were driven from the two headings, the monthly average being 232 ft. per heading. The best month's progress was 527 ft. from two headings; the best week's progress was 143 ft. from two headings; the best month's progress from a single heading (east) was 301 ft. The rock was medium hard granite, very seamy and very wet. Although hard to drill and blast, the granite disintegrated so rapidly that a temporary timber lining was necessary throughout, and it was afterward replaced with concrete.

The work was all done by day labor, no contracts being let, and, in consequence, it cost considerably more than would have been the case had it been built by contract. Three 8-hr. shifts were worked. There were 600 to 800 men employed, and they were not very efficient.

Four columns in a heading carried 6 drills (3¼-in. size). From 24 to 28 holes were drilled 12 ft. in the heading, and fired in three rounds by electricity. Including the bench work there were 14 drills used at each end of the tunnel. Rock from the heading and top bench was wheeled in barrows out onto the "jumbo," or "go devil," and dumped through into cars below. A compressed air hoist on the "jumbo" served to lift large rock and to shift the "jumbo" back before firing. Eight electric motor cars were used to haul the muck, etc. One motor hauled 16 to 20 dump cars of 1 cu. yd. each up the 1.7% grade to the east portal, at 10 miles an hour. The rails were 50-lb. rails laid to a gage of 2 ft.

Large power houses were built at each portal. The east power house contained 1 Ingersoll-Sergeant duplex compressor, 18 x 24

ins.; 1 straight line compressor, 18 x 24 ins.; 1 Rand duplex compressor, 20 x 36 ins.; 1 Buckeye high-speed engine, 12 x 16 ins.; 1 Chandler & Taylor high-speed engine, 13 x 14 ins.; 6 150-hp. boilers; pumps, dynamos, fans and water heaters. Compressed air was delivered through 6-in. mains to the drills, at an initial pressure of 100 lbs.

The tunnel was lined with concrete from end to end, the temporary timber lining being removed. The concrete is nowhere less than 2 ft., and in places it is 3½ ft. thick; spawls and broken stone were packed above the concrete where necessary. To place the concrete without interfering with the muck trains, a platform 500 ft. long was erected, and the cars loaded with concrete were hauled up an incline by a compressed air hoist. The concrete was dumped on the platform and shoveled into the forms. While this was going on another 500-ft. platform was being built in advance. Side walls were built in alternate sections 8 to 12 ft. long, the weight of the timber arches being thus transferred to the walls. The concrete arch centers were made in 12-ft. lengths, of which there were 10 in each end of the tunnel. When the concrete had set, the 12-ft. arch center was lowered with screw jacks onto "dollies," pushed forward 12 ft. and jacked up again. Concrete was mixed, 1 cement, 3 sand and 5 parts rock. About 95,000 bbls. of Portland cement were used in lining the tunnel, an average of 7 bbls. per lin. ft. of tunnel. Work of lining was begun in December, 1899, and finished November, 1900; more than 1,000 ft. of lining having been placed in October, 1900, in the west end, although the general average was about 600 ft. of lining per month from each end. The tunnel was opened for operation Dec. 20, 1900.

Mr. Willard Beahan says that it was a serious mistake to have driven the heading in rock by hand 300 ft. in advance of the bench while waiting for the power plant to arrive, for the long heading overtaxed the transportation so that work on the heading had to be stopped until the bench was brought up. The use of four drill columns he regards as novel, and adds that there was plenty of room in which to work six drills, and that it was not necessary to shift any of the columns in drilling a set of holes.

The actual cost of this tunnel, as originally printed in *Engineering-Contracting*, Dec. 8, 1908, was as follows:

	Per lin. ft.
Engineering	$ 4.30
Labor excavating tunnel	60.60
Explosives	7.40
Power	22.50
Tools ($137,000)	10.00
Machinery ($223,000)	16.20
Buildings	3.50
Timber lining	9.40
Concrete lining	43.50
Personal injuries	2.10
Hospital expenses	1.10
Permanent track through tunnel	2.80
Total	$183.40

A comparison of this cost with that of the Stampede Tunnel, through the same mountain range, shows that the Stampede Tunnel was built at less cost, although high contract prices were paid.

Wabash R. R. Tunnels.*—I am indebted to Mr. T. H. Loomis, Div. Eng. P., T. & W. R. R. (Wabash system) for much of the following data kindly furnished by him when I went over the line in 1903 studying the methods and cost of excavation. Eight double-track tunnels were under way, the cross-section of each being as shown in Fig. 1. The material encountered was shale, sandstone, fire clay and occasional seams of coal—characteristic of eastern Ohio and western Pennsylvania. The section above the wall plates (i. e., the longitudinal timbers on top of the posts) requires an ex-

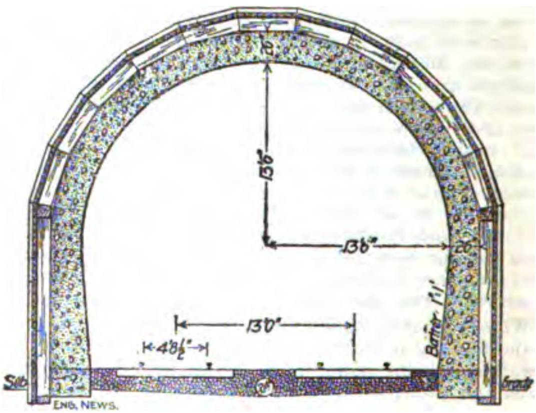


Fig. 1.—Double Track Tunnel.

cavation of 15 cu. yds. per lin. ft. The clear width between wall plates is 34¼ ft. The segmental arch timbers are 12 x 12 ins., lagged with 4-in. plank, the arch ribs being 3 to 4 ft. c. to c. The favorite method of attack, as shown in Fig. 2, was by what I will term the twin-heading method; two 8 x 8-ft. headings being driven as shown, and afterward enlarged. The floor of these headings is 12½ ft. above subgrade, thus leaving a 12½-ft. bench, *A C D B*, to be taken out. One machine drill is operated in each heading (two could be worked) for the drilling is easy. The rivalry between the two drilling gangs in these twin headings appeared to me to be one of the best features of this method of attack. It is certain that no hitherto published data show as low a cost per cubic yard for tunnel work as the data which I secured on this work. The weekly

*Gillette's "Rock Excavation."

progress was not rapid, but, as all the tunnels were comparatively short, there was no necessity of going to great expense in securing rapid progress—a fact that tunnel contractors should bear in mind. Steam drills were used in some of the short tunnels. The following is the actual cost of excavating and timbering the section of a tunnel above the wall plates (15 cu. yds. per lin. ft.), using air drills, for a distance of 100 lin. ft.:

Labor	$2,527.45
2,000 lbs. 40% dynamite, at 12 cts.	260.00
470 gals. kerosene oil, at 12 cts.	56.40
1,875 gals. gasoline, at 12 cts.	225.00
3,000 bus. coal for compressor, at 9 cts.	270.00
Machine and lubricating oils	62.50
Blacksmith shop	150.00
41,649 ft. B. M. timber, at $23	957.93
Total cost of 100 lin. ft.	$4,509.28
Cost per lin ft. above wall plates	45.09
Cost per cu. yd. including timber	3.06
Cost per cu. yd., excluding timber	2.60

The material in this case was sandstone.

On another tunnel the section above the wall plates was excavated by hand at a cost $40.90 per lin. ft., or $2.73 per cu. yd., for a distance of 110 ft., the material being hard fire clay in the upper half and shale in the lower half of the section excavated, making easier excavation than in the sandstone. The force engaged in hand drilling, by the twin-heading method, was:

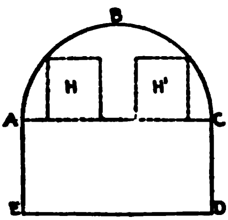


Fig. 2.

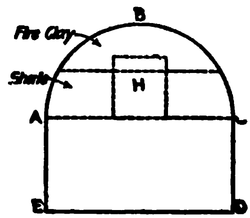


Fig. 3.

	Wages per 10-hr. shift.
1 general foreman	$ 4
1 foreman	3
1 blacksmith	3
2 carpenters, at $3	6
10 miners, at $2	20
10 muckers, at $1.50	15
1 team	4
Total per shift (10-hr.)	$55

While these men took out the whole section above the wall plates (16 cu. yds. per lin. ft.) for $2.73 per cu. yd. for labor and explosives (not including cost of timber), working in shale and fire

clay, they excavated a 7 x 8-ft. heading in sandstone for $3.75 per cu. yd., distributed as follows:

	Per 10-hr. shift.
Labor on 7 x 8 heading	$18.00
Dynamite	3.84
Repairs	.90
Light	.32
Total per shift	$23.06

Each shift excavated 6.2 cu. yds. of this 7 x 8-ft. heading, making the cost $3.75 per cu. yd., as above stated, equivalent to an advance of 3 ft. per shift.

No night shifts were being worked on the eight tunnels, and the progress per week in shale was 25 ft. when working by hand and excavating 15 cu. yds. per lin. ft.; and 50 ft. a week working with machine drills. In hard sandstone the weekly progress was about 15 ft. by hand and 30 ft. with machine drills, in all cases working only 1 10-hr. shift in the 24-hr. day.

The following is the actual cost of timbering on one job:

	Per M.
Georgia pine f. o. b. cars	$23.60
Hauling 6 miles	3.00
Cost of framing	5.00
Cost of erecting	3.00
Total per 1,000 ft. B. M.	$34.60

The carpenters received $3 per 10-hr. day, and laborers erecting received $1.50. The cost of framing and erecting, including supervision, was $8 per M, which was about $2 more than it should have cost had there been more workers and fewer bosses. Over the rough roads each team hauled about 1,000 ft. B. M. per load and made one trip of 6 miles each way in a day. The cost of "packing" (i. e., placing small stones) above the lagging was 80 cts. per cu. yd.

We now come to what I have said are the lowest records of tunneling cost yet made public:

Tunnel heading in sandstone, double track full section above the wall plate grade (15 cu. yds. per lin. ft.):

	Cu. yd.
Drilling	$0.60
Explosives	.40
Mucking	.85
Total	$1.85

Tunnel bench in same tunnel:

	Cu. yd.
Drilling	$0.40
Explosives	.20
Mucking	.22
Total	$0.82

The sandstone was very hard, breaking in large blocks, which have to be drilled and shot before mucking. A steam shovel is used in the bench, and material of heading is carried about 400 ft. and dumped over the breast of bench, whence steam shovel loads it along with bench material.

In another tunnel, in a formation of practically level strata of slate, limestone (thin) and fire clay (a stone hard as limestone to drill, but disintegrating in the air) the cost was as follows:

Heading—full double-track sections—all above wall plates:

	Cu. yd.
Drilling	$0.48
Explosives	.30
Mucking	.80
Total	$1.58

Bench—same tunnel—full section:

	Cu. yd.
Drilling	$0.30
Explosives	.20
Mucking	.18
Total	$0.68

In the case of another tunnel in coal formation with a 5-ft. vein of coal running all through on the wall plate grade; steam drills used in rock, and steam coal augers in the coal, with steam shovel for mucking, the costs were as follows:

Headings—per cubic yard—double track:

Labor	$0.966
Explosives and materials	.090
Total	$1.056

Bench—same tunnel and formation:

	Cu. yd.
Labor	$0.38
Explosives and materials	.04
Total	$0.42

This last may seem too low, but it was in all probability the cheapest material a tunnel is ever built in, and the organization was so good that it was worked with extreme economy. A core of about 2 cu. yds. per lin. ft. was left in the middle of the heading (between the twin headings) and taken out along with the bench.

Mount Wood and Top Mill Tunnels.—Mr. W. J. Yoder gives the following data: The tunnels (built in 1888-1889) are within the northern city limits of Wheeling, W. Va., and the material penetrated was for the most part shale of the coal measures. The shale disintegrates rapidly upon exposure and must be supported. The block or American system of timbering was used for lining, and was kept never more than 50 ft. back of the face. All drilling was done by hand. A top heading 10 x 34 ft. was driven, and then widened; the bench was taken out in two lifts. The first or cut holes in the heading were drilled so as to blast out a long horizontal wedge

of rock near the roof; these holes being 5 to 6 ft. deep. Then a lower row of 5-ft. lift holes was fired. Finally the bottom of the heading was taken out like a bench by a row of vertical holes and a row of horizontal holes. In all 33 holes were fired in the heading, aggregating 160 lin. ft., and requiring 60 lbs. of 40% Forcite to load them. The effect of the firing was to make an advance of 2½ ft., displacing 25 cu. yds. [The heading gang consisted of 1 foreman, 14 drillers, 12 muckers and 1 nipper.] About 25 lin. ft. of drilling was considered a day's (10 hrs.) work for 2 men. The muck was wheeled in iron barrows to a traveler and dumped down chutes into cars. The heading gang timbered and placed the packing above the arch; two 10-hr. shifts per week being needed for this work, leaving 10 shifts per week for advancing the heading. The timbering is fully described; 660 ft. B. M. of white oak were used per lin. ft. of tunnel. The bench holes were 8 ft. deep, churn drills being used except for the corner holes and for blockholing. The bench force consisted of 1 foreman, 6 drillers, 18 muckers, 2 mule drivers, 3 dump men and 1 nipper. The average haul was about 800 ft.

The maximum monthly progress (working two 10-hr. shifts) in a heading on the Mount Wood Tunnel was 130 lin. ft., the average monthly progress being 84 ft. The maximum monthly progress on the bench was 125½ ft., the average being 97 ft. The average excavation was 10.2 cu. yds. per lin. ft, of heading and enlargement, and 18 cu. yds. per lin. ft. of bench. The total excavation in both tunnels was 49,670 cu. yds., and the excavation in approaches was 25,751 cu. yds.

The number of men employed was 350. The heading men were composed of two-thirds negroes and one-third Austrians. The foremen were Irish. The best drillers were negroes. No work was done Sundays or Saturday nights. The scale of wages (10-hr. shift) was as follows:

HEADING GANG.

1 foreman	$4.00
14 drillers	1.75
10 muckers	1.50
1 nipper	1.25

BENCH GANG.

1 foreman	$3.00
6 drillers	1.75
16 muckers	1.50
2 men (lagging)	1.50
1 nipper	1.25
2 drivers	1.50
3 dumpmen	1.50
2 mules	....

MISCELLANEOUS.

1 carpenter	$2.50
4 sawyers	1.75
1 trackman	2.50
3 blacksmiths	3.00
1 walking boss	4.00
1 timekeeper	2.25
1 engineer and fireman	2.50
1 electrician	2.50

COST OF LABOR PER LIN. FT. OF TUNNEL.

Labor excavating (heading, $22.79; bench, $20.95)	$43.74
Hauling and dumping	5.65
Labor timbering	4.19
Labor framing timber	.77
Blacksmithing	1.00
Track repairs	.21
Labor electric lighting	.88
Superintendence and accounts	2.00
Total labor	$58.44
Cost per cu. yd.	2.06

The above does not include the cost of timber, oil, fuel, wear of tools or explosives. About 1 lb. of 40% Forcite was used per cu. yd. of tunnel excavation, or 28 lbs. per lin. ft. The labor cost was $2.34 per cu. yd. of heading, and $1.10 per cu. yd. of bench excavation, making an average of $1.55 per cu. yd., not including the items of timbering, etc. The labor cost of erecting arch and packing back of it was $3.19 per lin. ft. of tunnel; or $7.80 per 1,000 ft. B. M. The labor cost of erecting plumb posts and side lagging and packing same was $2.33 per lin. ft.; or $4.27 per 1,000 ft. B. M. The contractors were Paige, Carey & Co., of New York, whose superintendent was Mr. Frank Moran.

Tunnel Driven by Hand on the B. & O.—Mr. J. G. G. Kerry gives description and cost of a short single-track tunnel built in 1891 on the W. Va. & P. R. R., a feeder of the B. & O. system. The tunnel is on a ¼% grade falling to the south, with a length of 624 ft., in a soft blue clay shale, nearly dry and showing little stratification. This shale disintegrates rapidly on exposure. The width was 23 ft., height from floor to spring line 13 ft.; semi-circular arch of 11½ ft. radius. The area of the heading was 208 sq. ft.; bench, 299 sq. ft.; total, 507 sq. ft. Work was all done by hand. The heading gang consisted of 1 foreman, 8 miners, 6 muckers and 1 nipper. Common laborers were paid $1.45 and miners $1.75 per 10-hr. day. Three sets of holes (2 wet and 1 dry) were drilled in the heading; each set consisting of 4 holes about 4 ft. deep; and 24 ft. of holes was considered a good day's work for two miners. Each hole was loaded with 4 to 6 sticks (⅓ lb. per stick) of dynamite; and the average advance from a blast was 2½ ft. A scaffold car, or go-devil, was used in handling the muck. It was provided with a derrick and also used for handling timbers, lagging and packing.

The bench gang consisted of 1 foreman, 8 drillers, 10 muckers and 1 nipper. The bench was shot down in 4-ft. holds or lifts, two half-depth blasts being made for each hold. Each blast consisted of four holes, two being center holes, and two nearly vertical under the wall plate. The charge was 10 sticks to an outside hole and 15 sticks to a center hole. Muck was taken out in 1 cu. yd. dump cars in trains of two. Stone flat cars with platforms flush with top of wheels were used for handling large rocks. The bench was kept two wall plate lengths behind the heading, making

the same progress, 2½ ft. per shift. The actual excavation was at the rate of 5 ft. per shift, but the time consumed in pointing down projections, timbering and packing being equal to the time spent in excavation, reduced the average progress to 2½ ft. per shift. The work was done by contract, and it cost the company at contract prices as follows:

11,726 cu. yds. of excavation at $2.85	$33,419
742 cu. yds. of packing, at $1.75	1,298
256 cu. yds. of fallen rock, at $1.25	320
303,000 ft. B. M., at $30.00	9,090
Total 624 lin. ft. of tunnel, at $70.70	$44,127

The actual cost to the contractor was about $35,000.

The method of handling and placing the segmental arch timbering is described in detail. The timbering consisted of a 7-segment arch of 12 x 12-in. white oak resting on 12 x 14-in. wall plates on top of the posts. The 16-ft. wall plates were jointed by halving for a foot at each end, so that the forward end always showed the lower half of the joint. The arches were 8 ft. c. to c. The segments of the arches were erected on temporary centers made of 2-in. plank. These centers were erected in two parts and joined at the crown by bolts; a long dog-hook, fastened to the center, was driven into the preceding arch to hold it in place laterally. The arch timbers were wedged solidly against the roof, and the centers withdrawn. The lagging was close laid, all voids being packed with broken sandstone.

Each end of the tunnel was lined with masonry for 50 ft., the centers used in this lining being 25 ft. long and mounted on rollers. During use the centers were supported on wedges, which upon being struck lowered the center enough to clear the rock-faced voussoirs. A hole was left in the crown of the arch-center lagging so that the voussoirs could pass through. Above this a piece or two of the tunnel lagging was removed, and an iron bar placed on the timber arches. A set of blocks was hung from this iron bar, and used to raise the voussoir stone. Gas pipe rollers were put under the stone to roll it to place on the center lagging. The stone was then canted up, and a rope slung around it, six men then sliding it to place.

The contract prices were $9 per cu. yd. for portal masonry, $8 for side walls and $14 for arch sheeting. The cost at contract prices per lin. ft. of that part of the tunnel which was lined (excluding portals, fallen material, etc.), was:

	Per lin. ft.
Excavation, at $2.85 per cu. yd.	$ 53.55
Packing, at $1.75 per cu. yd.	2.08
Timbering, at $30.00 per M	14.75
Side walls	20.56
Arch	21.42
Total per lin. ft.	$112.36

Cost of the Busk Tunnel.—The Busk Tunnel Ry. Co. built a tunnel 9,395 ft. long on the Colorado Midland R. R. through the Rocky Mts., 11.7 miles S. W. of Leadville. The contract was let to Keefe & Co., and work was begun Sept. 15, 1890. After all but 921 ft. had been driven the work was turned over to the railway company and finished under the direction of their chief engineer, Mr. B. H. Bryant. The tunnel is single track, 15 x 21 ft., with 10.2 cu. yds. per lin. ft. excavation in rock and 13.8 cu. yds. where timbered. The heading was 7 ft. high and the full width of the tunnel. The first 8 holes, 8 ft. deep, were drilled in two rows from the top to bottom, holes being about 2 ft. apart at surface and converging toward the center. The firing of these holes made a V-shaped opening. A second set of holes was drilled parallel to the sides of the tunnel, and when fired the remaining rock was blown into the V-shaped opening. The bench was excavated in the same way. The progress was as follows:

Driving the 2 headings	1,118 days
Av. daily progress	8.4 ft.
Av. daily progress, best month	10.9 ft.
Best month's (28 days) progress, 1 heading	202.5 ft.

The rock was granite, and in places it disintegrated on exposure, requiring timbering; in other places it was so full of seams as to require timbering; so that 78 per cent of the tunnel was timbered. The contractor was paid for the tunnel as follows:

9,393¾ ft. of tunnel at $62.50	$587,103.75
32,575 cu. yds. enlargement for timbering at $2.50	81,437.50
Cost of timber, 2,723,000 ft. B. M. at $30	81,690.00
Labor timbering at $12 per M.	32,676.00
Total 9,393¾ ft. at $82.30	$782,907.50

The plant at the Ivanhoe end consisted of three 100 hp. boilers, two 20 x 24-in. Ingersoll compressors, one 20 x 24-in. Norwalk compressor, one 10 hp. engine to drive electric light dynamo, one 20 hp. engine to drive a No. 6 Blake blower, 14-in. air pipe, two pumps with 14-in. steam cylinders and 10-in. stroke, six 3⅛-in. Ingersoll drills (4 in the heading and 2 on the bench), a small traction engine running on a 20-in. gauge track hauling nine 3-yd. dump cars. Coke was used as fuel for the traction engine, so that the smoke did not inconvenience the tunnel workmen.

Cost of a Tunnel Near Peekskill, N. Y.—The following data are given by Mr. Geo. W. Lee, engineer for Sundstrom & Stratton, the contractors who built the double track tunnel described. The tunnel is only 275 ft. long, and is on the line of the New York Central R. R., 2½ miles north of Peekskill. The yardage as shown on the plans was 7,028 cu. yds., but as the rock lay in strata dipping at an angle of 45°, it broke out on the uphill side so as to leave large pockets, in consequence of which the contractor took out 10 per cent more rock than he was paid for. Owing to the seamy condition of the rock, and the proximity of the tunnel to the main line traffic, very light charges of dynamite were used, which

increased the cost and delayed the progress. Rand steam drills, 3-in., were used. A heading 8 x 10 ft. was run and the bench was kept close behind. Rock from the heading was removed in small narrow gage cars; rock from the bench was loaded into standard gage cars by derrick cars. The following was the cost of the tunnel excavation:

Equipment (less present value), supplies and repairs	$ 2,893.52
Dynamite and exploders	1,604.58
Coal	570.80
Oil, waste, etc.	92.80
Lumber for houses and shops	129.88
Miscellaneous	92.10
Labor	22,212.86
Total	$27,596.54
Average cost per cu. yd. paid for	3.93
Average cost per cu. yd. taken out	3.54

The tunnel was lined with 1:2:4 concrete; 692 cu. yds. in the bench walls; 932 cu. yds. in the arch; the portal head walls were of 1:3:6 concrete, 324 cu. yds. The cost of the concrete was as follows for the 1,948 cu. yds.:

Cement at $1.63 per bbl.		$ 5,755.50
Sand at 75 cts. per cu. yd.		662.94
Crushed stone at 80 cts. per cu. yd.		1,303.20
Lumber.		
Mixing platforms and runways	$336.89	
Ribs, including hand sawing	234.10	
Backing boards	134.44	
Lagging	341.04	
Sheathing	268.49	
Plates, sills, studs and braces	182.75	
		1,497.71
Coal		118.73
Oil		16.12
Hardware, nails, spikes, etc.		224.39
Tools		181.10
Freight on stone, cement, etc.		3,089.86
Labor, including supt., foreman, etc.		8,036.31
Total, $10.72 per cu. yd.		$20,885.86

In the approaches to the tunnel and in widening cuts south of the tunnel 45,698 cu. yds. of rock were removed. On account of proximity to traffic, blasting could be done only at limited periods, which made the cost of excavation high. Rock was loaded on flat cars with stiff leg derricks provided with bull wheels. The cost was as follows:

Equipment (less present value, supplies and repairs	$11,673.60
Dynamite and exploders	6,588.82
Coal	2,490.13
Oil, waste, etc.	370.59
Lumber for buildings	634.22
Miscellaneous	373.19
Labor	69,550.66
Total	$91,681.21
Average cost per cu. yd. paid for	2.24
Average cost per cu. yd. taken out	2.01

Cost of Tunnelling, Alaska Central Railway.—From data compiled by Mr. G. A. Kyle, and given in a great detail in *Engineering-Contracting*, April 7, 1909, I have prepared the following condensed summary.

The work comprises seven short tunnels located on the Alaska Central Ry., between miles 48 and 52. The work was begun by a contracting firm, but taken over by the railway and finished with company forces. The costs are all high, not only because wages were high and because of location in an inaccessible country, but because work done with company forces is almost invariably more expensive than work done by contract.

Table I shows the length of each tunnel, and the cross-section. It is worthy of note that the "overbreak" averaged 12.1%. The rock was a "hard blocky slate with fractures at right angles to the axis of the tunnels." It broke easily and almost to the theoretical lines of the tunnel, and required no timbering.

The standard cross-section was 14 ft. between side walls and 21 ft. between top of rail and top of tunnel.

Tunnel No. 1 was built by company forces and was begun Jan. 16, 1906. This tunnel was located 1¼ miles from the end of completed track. The tunnel was driven entirely from the north end on account of a snow slide on the south end, making it impossible to work on that end, as the work was mostly done in the winter months. The tunnel is 699 ft. long. The first 250 ft. was driven with steam power and drills. The character of material is of a hard rocky slate and is evidently in an ancient slide from the mountains, as the strata were badly broken up, which caused a great amount of overbreak outside of the standard sections, the same being 27 per cent. This tunnel was on a 14° curve and was widened to give a minimum clearance of 18 ins. for the maximum length passenger car. The size of the tunnel was 17 ft. wide between timbers, and 21 ft. from top of rail to clearance at top of tunnel. Timber was used for 396 ft. in the north end. The balance was left unlined, but later had to be lined nearly its whole length at an extra high cost, which is not included in the costs as shown below.

The steam plant used in driving the first 250 ft. of the tunnel was one 40 hp. boiler, one 10 hp. boiler; three 3¼-in. Rand drills were used in the heading. The work carried on with the following

TABLE I—STATISTICS OF TUNNELS, ALASKA CENTRAL RY., SHOWING DIMENSIONS, QUANTITIES, ETC.

	Length		Quantities, cubic yards — Totals			Quantities, cubic yards — Per lin. ft.			
No. tunnel.	Partial ft.	Total ft.	Standard cross section.	Over-break.	Total cross section.	Standard cross section.	Over-break.	Total cross section.	Per cent. Overbreak in tunnel Excavation.
1	....	699	10,186	2,800	12,986	14.572	4.006	18.578	27%
2	....	300	3,622	300	3,922	12.072	1.000	13.072	2.3%
3	776	....	.....	....	.....	.....	....	.....	...
3	179	955	10,241	600	10,841	10.723	.505	11.228	5.8%
4	127	....	.....	....	.....	.....	....	.....	...
4	287	414	4,539	200	4,739	10.964	.483	11.447	4.4%
5	....	304	3,444	282	3,726	11.329	.928	12.257	11.1%
6	....	193	2,630	200	2,380	13.626	1.037	14.663	7.1%
7	196	....	.....	....	.....	.....	....	.....	...
7	200	....	.....	....	.....	.....	....	.....	...
7	180	576	6,986	678	7,664	12.128	1.178	13.306	9.1%
						Average yardage per ft.			Average.
Totals	1,945	3,441	41,648	5,060	46,708	12.074	1.500	13.574	12.1%

force in each shift of 10 hours (although work was carried on with day and night shifts during a short period):

1 foreman.
3 machine drillers.
3 machine driller helpers.
1 muck boss.
10 muckers, 2 in head and 8 on bench.
1 light tender.
1 man on dump.
1 man on cars.
1 horse.
1 engineer.
1 fireman.
1 blacksmith.

Making 24 men and 1 horse per shift.

The timbering was not kept up with the bench, as the material stood sufficiently well for the men to work, although it was considered dangerous at times.

There were used in blasting 21 or 22 holes in the heading 8 to 10 ft. deep, and the bench was taken out in two lifts generally. The heading was run from 40 to 60 ft. ahead of the bench and scaffolding used to dump the muck from heading directly into the cars from above, two plank runways supported on trestle being used for the purpose.

The steam plant was discontinued on April 14, 1906, as the heat from the escaping steam at the drills made the tunnel too hot for the men to work. The progress with the steam plant was satisfactory with the above exception and seemed to be about the limit that steam can be used economically, viz., 250 ft. from the end of tunnel. The steam was carried from the boilers to the drills in a 2½-in. pipe and the escaping steam was carried from the drills back out of the tunnels in a 2-in. pipe enclosed in a wooden box with the 2½-in. steam pipe to decrease the heat. The progress during the 84 days that the steam plant was used was 250 ft., and the progress made while the air drills were working was about 26 ft. per day, so that about the same progress was made during the steam plant's operation as with the air plant, which was 26.2 ft. This might be accounted for by the fact that from the time that the steam plant was discontinued, April 14, 1906, until April 28, 1906 (14 days), when the air plant was started, there was not much work done in the tunnel excepting to work on the bench, which was considerably behind at that time. From the time the air plant was installed until Sept. 25, 1906, 150 days, the tunnel was worked continuously and was practically finished. The time from Sept. 25 to Oct. 8, the time that the tunnel is shown as completed in Table II, was employed in dressing up and completing the timbering of tunnel. The actual days worked on the tunnel were 234, making the actual progress while work was going on 3 ft. per day. Considerable trouble was had in keeping the force

TABLE II—SHOWING PROGRESS ON ALL TUNNELS AND OTHER INFORMATION REGARDING SAME.

Item.	Tunnel No. 1.	Tunnel No. 2.	Tunnel No. 3 South end.	Tunnel No. 3 North end.	Tunnel No. 4.	Tunnel No. 5.	Tunnel No. 6.	Tunnel No. 7.
Date work commenced	Jan. 16-06	Dec. 20-05	Dec. 14-05	Feb. 28-06	June 21-06	Dec. 24-05	June 18-06	May 24-06
Date work finished	Oct. 8-06	May 12-06	July 11-06	July 11-06	Nov. 30-06	May 16-06	Nov. 7-06	Nov. 4-06
Total days required to complete tunnel	265	143	210	133	162	143	142	164
Date steam plant was started	Jan. 20-06	....	....	....	....	....	....	....
Date steam plant was burned	Apr. 14-06	....	....	....	....	....	....	....
Total days steam plant worked	84	....	....	....	....	....	....	....
Date started air plant	Apr. 28-06	Dec. 20-05	Feb. 28-06	Feb. 28-06	....	....	June 18-06	May 24-06
Date completion with air plant	Sept. 25-06	May 12-06	July 11-06	July 11-06	....	....	Oct. 15-06	Oct. 15-06
Total days use of air plant	150	143	133	133	....	....	120	145
Greatest weekly progress	28	32.5	43	50	28	23.5	26	49
Smallest weekly progress	21	20.	23	26.5	16.5	18	20	28
Average weekly progress while actually at work	24.5	26.2	33	35.7	20.5	21.1	14.3	40.1

Greatest monthly progress while actually at work.....	117.2	120.4	162.5	185	96.5	94.3	93.5	176.
Smallest monthly progress while actually at work.....	92.8	109.	140.	130.5	92.	89.	35.	168.
Average monthly progress while actually at work.....	108	112.3	141.4	153.	88.	90.4	64.3	172.
Average daily progress figuring from time air was used	......	3.46	3.20	3.20	....	....	1.61	3.97
Average daily progress beginning to finish	2.64	2.09	2.52	3.20	2.57	2.13	1.36	3.51
How built..........	Company Steam and Air	Company Air	Company Air	Company Air	Contract By Hand	Contract By Hand	Company Air	Company Air
No. of headings worked at once...	1	1	1	1	1	1	1	2
Length of tunnel...	699	300	529	426	414	304	193	576
Bonus paid to all employes, 50c per foot for every foot in each heading in excess of number of feet shown under each tunnel per week of seven days	24.5	32.0	32.0	32.0	....	....	35.0	35.0

up to the standard number in this tunnel on account of the dangerous character of the rock.

The cost of this tunnel was as shown in Table III (the length being 699 ft., involving 12,988 cu. yds. excavation):

TABLE III—COST OF TUNNEL.

	Per lin. ft.	Per cu. yd.
Compressor and Steam Plant.		
Lighting compressor house, 125 gals. oil at 40c....$	0.072	$0.004
Dep. of boilers comp. plant drills, etc., 30% of original cost at end of track	3.044	0.164
Lubricating oil for compressor	0.086	0.005
Freighting machinery for plant, 25 tons at 50c per ton mile	0.072	0.004
Lubricating oils for drills	0.046	0.002
Machinist repairing plant	0.153	0.008
Building for compressor plant (mtls. $184, labor $330)	0.470	0.025
Total compressor and steam plant............$	3.943	$0.212
Fuel.		
Coal at end of track (266 tons at $8.80)...........$	3.346	$0.181
Freighting 266 tons coal from end of track, at 50c per ton mile	0.761	0.041
Miscellaneous labor hauling coal and ashes 8 mos. at $85.00	0.972	0.052
Horses, hauling coal and ashes 8 mos., at $48.00	0.549	0.030
Total fuel..............................$	5.628	$0.304
Enginemen, Etc.—Compr. Plant.		
5 mos. engrs., at $250 per mo. (2 men)...........$	1.788	$0.096
150 days firemen, at $3.00	0.644	0.035
82 days firemen, at $6.00 (2 men)	0.704	0.038
Total engineers and firemen.................$	3.136	$0.169
Pipe Line.		
Dep. of pipe line and fittings, 60% of 1st cost......$	0.359	$0.019
Hose and parts, 1st cost	1.762	0.095
Laying pipe line, 800 ft. at 20c	0.229	0.012
Total pipe line...........................$	2.350	$0.126
Lighting Tunnel.		
Candles ....$	0.705	$0.038
Coal oil	1.043	0.056
Gasoline	0.300	0.016
Buckeye lights and torches (dep., 50% of $160, first cost)	0.113	0.006
Freight hauling 17 tons 4 miles, at 40c per ton mile	0.039	0.002
Labor, 245 days, attended lights, at $6 day	2.103	0.114
Total, lighting tunnel......................$	4.303	$0.232
Blacksmithing.		
265 days, at $9.00 (2 men)......................$	5.686	0.307
14.8 tons coal, at $20 per ton, at end of track	0.423	0.023
14.8 hauled from end track to tunnel, at 40c per ton mile, = $1.60 per ton	0.034	0.002
Depreciation of tools (50% of $316, first cost)	0.226	0.012
Total blacksmithing.......................$	6.369	$0.344

Engineering and Superintendence.		
Engineering	$ 2.861	$0.155
Superintendence	2.575	0.139
Total engineering and superintendence	$ 5.436	$0.294
Labor Excavating.		
Bonus	$ 2.111	$0.114
Labor, including shift bosses	76.226	4.116
Horses, 496 days at $1.50	1.064	0.058
Total labor in tunnel excavation	$ 79.401	4.288
Explosives.		
Explosives, powder	$ 11.273	$0.609
Fuses, caps, exploders, lead wires	1.072	0.059
Total explosives	$ 12.345	$0.668
Materials.		
Tools, hand	$ 0.193	$0.011
Tools, drill steel, dep. 50% first cost	0.317	0.017
Cars, tracks, dep.	0.556	0.030
Miscellaneous hardware and sundries	0.614	0.033
Lumber for scaffolding and miscl., 39,383 ft. B. M., at $12.00	0.684	0.037
Hauling above material, 112 tons, at $1.60	0.256	0.014
Total materials	$ 2.620	$0.142
Total making roads and trails	$ 1.717	$0.093
Total excavation	$ 96.083	.....
Total timber lining (see Table IV)	$ 11.205	$0.605
Total cost of tunnel	$138.453	$7.477

Summary.	Per lin. ft.	Per cu. yd.
Compressor and steam plant	$ 3.943	$0.212
Fuel compressor and steam plant	5.628	0.304
Engineers and firemen compressor plant	3.136	0.169
Total compressor plant	$ 12.707	$0.685
Pipe line connections, etc.	2.350	$.126
Grand total compressor plant	$ 15.057	$0.811
Lighting tunnel	4.303	0.232
Blacksmithing	6.369	0.344
Labor on excavation	79.401	4.288
Explosives	12.345	0.668
Material used in excavation for scaffolding, etc.	2.620	0.142
Roads and trails	1.717	0.093
Timber lining	11.205	0.605
Engineering and superintendence	5.436	0.294
Total cost of tunnel	$138.453	$7.477

There were 63.3 lbs. of dynamite used per lin. ft. of tunnel, or 3.57 lbs. per cu. yd.

There were nearly 30 lin. ft. of hole drilled per lin. ft. of tunnel, or 1.6 lin. ft. of drill hole per cu. yd. The extravagantly

expensive cost of this drilling is seen when reduced to the cost per lin. ft. of drill hole:

	Per ft. of hole.
Total compressor plant charges ($15.057 per lin. ft. of tunnel)	$0.51
Wages of drillers and helpers	0.23
Total per ft. of drill hole	$0.74

The plant used on this tunnel was as follows:

1 40 hp. firebox, water bottom boiler with stack injector and feed pump.

1 12x12x14 inch Franklin straight line air compressor, steam driven, capacity 350 cu. ft. of air per minute.

1 30-inch by 10 ft. air receiver.

750 ft. 4-inch gas pipe.

400 ft. 2½-inch gas pipe.

300 ft. 1-inch gas pipe.

450 ft. 1-inch armored rubber air hose.

150 ft. 2-inch armored rubber air hose.

2 3¼ Rand drills.

4 3⅛ Rand drills.

2 2¾ Rand drills.

5 tripods.

3 columns.

5 arms.

1,000 lbs. X steel.

Blacksmith outfit.

Pipe tools.

Pipe fittings.

Repair parts for drills.

TABLE IV—COST OF TIMBER LINING.

Company force, 148 ft. tunnel lining.	Total.	Per lin. ft.
80 cords wood, at $3.32 per cord	$ 266.57	.....
80 cords wood, at $3.00 per cord	240.00	.....
Total cord wood	$ 506.57	.....
5,400 ft. B. M. timber, at $22.22	1,199.88	.....
566 lbs. iron, at 5c	28.33	.....
5,400 ft. B. M. timber, at $12	648.00	.....
Total for timber	$1,876.21	.....
Total for 148 ft. lin. lining	$2,382.78	$16.010

Contract for 248 lin. ft.

952 lbs. iron, at 5c	47.60	$ 0.192
Lumber on hand	667.76	2.693
106,530 ft. B. M. timber, at $12, at end of track	1,278.36	5.154
106,550 ft. B. M. timber, at $20	2,130.60	8.591
Timber framed on hand	84.00	0.339
Total timber for 248 ft. tunnel	$4,208.32	$16.969
99.74 cords wood, at $4, labor	398.96	.....
90.56 cords wood, at $3, labor	271.68	.....
190.30 cords wood, at $3, material end track	570.90	.....
Total cords wood back filling	$1,241.54	$ 5.006
Cost of 248 lin. ft. lining	$5,449.86	$21.975
Total for 396 lin. ft. tunnel lining	$7,832.64	$19.782
Total for 699 lin. ft. tunnel lining	$7,832.64	$11.205

The wage scale was as follows:

Position.	Per month.	Per day.
Superintendent	*$300	...
Walking boss	* 175	...
Shift bosses	...	†$5.00
Muck bosses	...	† 4.00
Machine drillers	...	† 4.00
Machine helpers	...	† 3.00
Carpenters	...	† 4.00
Blacksmiths	...	† 4.50
Powder thawer	...	† 3.50
Machinist	† 125	....
Engineers	† 125	....
Firemen	...	† 3.00
Muckers	...	†2.75 to 3.00
Carmen	...	†2.75 to 3.00
Other general labor	...	† 2.75

*And board. †Paid their own board at $6 per week.

The prices of explosives were as follows:

	Per lb.
Dynamite, 70 per cent	$0.186
Dynamite, 60 per cent	0.170
Dynamite, 40 per cent	0.160
Black powder	.075
Champion powder	.110
Vigorite	.120
Trimiff	.110
	per 100.
Caps	$0.90
	Per 100 ft.
Fuse	$0.75
Electric exploders, 4′ to 14′ leads, average all lengths, 10 ft.	5.00

Tunnels Nos. 2, 3, 6 and 7.—The character of rock in all these tunnels was practically the same, being a hard blocky slate with fractures at right angles to the axis of tunnels. The rock drilled and broke easily and almost to the theoretical lines of the tunnel, and did not require any timbering, for the present at least.

The standard cross section was 14 ft. wide between side walls and 21 ft. between top of rails and clearance at top of tunnel.

The lighting was with torches and Wells standard lights, one of the latter in each face of tunnel, and gave good satisfaction, the electric lighting plant that was bought for the purpose not being used.

	Lbs.
Explosives used in these tunnels were	90,394
Per lineal foot of tunnel	44.7
Per cubic yard in tunnel	3.57
Per lineal foot of hole drilled in tunnel	1.46

The work was carried on in the same manner as tunnel No. 1, viz.: using 21 holes in the heading, 8 ft. deep, and the bench taken out generally in two lifts, the muck taken from the headings on wheelbarrows by two men and wheeled on planks supported by trestles and dumped directly into the cars from the wheelbarrows. The work was carried on in shifts of 10 hours each, part of the time day and night, with the following force in each shift, viz.:

1 horse.
1 foreman.
1 muck boss.
3 machine drillers.
3 machine driller helpers.
1 light tender.
8 muckers, 2 in heading, 6 on bench.
1 dump man.
1 car man.
1 blacksmith.
1 engineer.
1 fireman.
Making 23 men and 1 horse in all per shift.

When the company took these tunnels over from contractors, Mr. Martin Moran, who is an experienced tunnel man, was hired as general superintendent to look after the work.

There was also trouble in keeping men on these tunnels on account of scarcity of labor at that time, and a system of paying a bonus of so much per foot to each man connected with the work after a certain number of feet per day was driven, was put into effect, which is shown in Table II.

The actual work of driving tunnel No. 2 by air was begun Feb. 20, 1906, and finished May 12, 1906, requiring 81 days to complete the remaining 280 ft. or an average of 3.46 ft. per day.

Tunnel No. 3 was driven from both ends; from the south end 529 ft. and from the north end 426 ft. by air drills! 75 ft. of the south end was driven by hand, and the remaining 454 ft. by air drills. Work on the south end began with the air drills on Feb. 20, 1906, and finished July 11, 1906. The north end was begun Feb. 28 and finished July 11, 1906, an average of 3.20 lin. ft. per day on the south end and the same on the north end.

Tunnel No. 6 was begun with air June 18, 1906, and finished Oct. 15, 1906, requiring 120 days to finish at an average per day of 1.61 lin. ft. The slow progress of this tunnel is evidently on account of the lack of power to run three headings at a time, as they were working in tunnel No. 7 at both ends at the same time, and it was impossible to carry all the headings on full force at once.

Tunnel No. 7 was driven from both ends at once time, but the exact data are not available to segregate the number of feet driven on each end. This tunnel was begun May 24, 1906, and finished Nov. 4, 1906, requiring 145 days to complete at an average of 4 ft. per day.

See Table II for other data. Wages and prices of materials were the same as for tunnel No. 1, above given.

These four tunnels (Nos. 2, 3, 6 and 7) had a total length of 2,024 ft., involving the excavation of 25,257 cu. yds. of rock. There were 31.5 ft. of drill hole per lin. ft. of tunnel, or 2.43 ft. of drill hole per cu. yd.

The itemized cost of the work on these four tunnels averaged as given in Table V.

TABLE V.—AVERAGE COST OF 4 TUNNELS.

	Per lin. ft.	Per cu. yd.
Compressor Plant:		
Dep. compressor plant, interest, etc. (30% first cost	$ 2.402	$0.192
Lubricating oil for compressor	0.032	0.003
Compressor building	0.207	0.016
Machinist labor repairing plant	0.092	0.007
Freighting machinery (60 tons, at $2.50)	0.074	0.006
Lighting compressor building (125 gals. coal oil, at 40 cts.)	0.024	0.002
Total compressor plant	$ 2.831	$0.226
Pipe Line:		
Pipe and fittings (60% first cost, for dep. and interest)	0.563	0.045
Hose and parts	0.246	0.020
Lubricating oil for drills	0.059	0.005
Laying pipe line from compressor to tunnels	0.673	0.054
Hauling (35 tons pipe, at $2.50)	0.043	0.003
Total pipe line	$ 1.584	$0.127
Fuel:		
Coal at end of track (980 tons, at $8.80)	$ 4.261	$0.341
Hauling (at $2.50 per ton)	1.211	0.097
Miscellaneous labor hauling coal and ashes (8 mos., at $125)	0.494	0.039
Fire wood	0.138	0.011
Horses hauling coal and ashes, at compressor 8 mos., at $72)	0.284	0.023
Total fuel for compressor	$ 6.388	$0.511
Enginemen, Etc.:		
Engineers (8 mos., at $250)	$ 0.988	$0.079
2 firemen (245 days, at $6.00 per day)	0.726	0.058
Total engineers and firemen	$ 1.714	$0.137

Excavating:		
Bonus	$ 1.853	$0.1482
Labor, including shift bosses and muck bosses	50.845	4.0676
Horses on cars, etc.	0.563	0.0451
Total labor on tunnels	$53.261	$4.2609
Total roads and trails	$ 0.791	$0.0633
Explosives:		
Explosives—powder	$ 7.593	$0.608
Fuse, caps, exploders, lead wire, etc.	0.722	0.057
Total explosives	$ 8.315	$0.665
Tools:		
Hand tools	$ 0.130	$0.010
Drill steel (50% original cost for dep.)	0.214	0.017
Cars, tracks, etc., depreciation	0.374	0.030
Total tools	$ 0.718	$0.057
Materials:		
Miscellaneous hardware and sundries	$ 0.414	$0.033
Lumber for scaffolding (77,837 ft. B. M., at $12)	0.461	0.037
Hauling (216 tons lumber, at $2.50)	0.267	0.021
Total lumber and hardware	$ 1.142	$0.091
Engineering, Etc.:		
Superintendence	$ 1.253	$0.100
Engineering	1.778	0.142
Total engineering and superintendence	$ 3.031	$0.242
Lighting:		
Candles	$ 0.474	$0.038
Coal oil	0.704	0.056
Gasoline	0.202	0.016
Buckeye lights and torches (50% original cost dep. and interest)	0.077	0.006
Hauling (33 tons at $2.50 per ton, 5 mi.)	0.041	0.003
Labor attending lights (245 days, at $6)	0.726	0.058
Total lighting tunnel	$ 2.224	$0.177
Blacksmithing:		
284 days blacksmithing, at $4.50	$ 0.631	$0.050
500 days blacksmithing, at $4.00	0.988	0.079
663 days blacksmithing at $3.00	0.983	0.079
19.82 tons blacksmith coal, at $20.00 end track	0.196	0.016
19.82 tons freight same, $2.50 per ton	0.025	0.002
Blacksmith tools, dep. 50% cost	0.104	0.008
Total blacksmithing	$ 2.927	$0.234
Grand total	$84.927	$6.791

The following is a summary of the foregoing:

	Per lin. ft.	Per cu. yd.
Compressor Plant:		
Machinery dep., lighting, frt. on same, etc.	$ 2.831	$0.226
Fuel for compressor	6.388	0.511
Engineer and fireman	1.714	0.137
Total compressor plant	$10.933	$0.874
Pipe line	$ 1.584	$0.127

Excavating:

Tools	$ 0.718	$0.057
Labor (compressor plant, drilling, etc.)	53.261	4.261
Roads and trails	0.791	0.063
Explosives, cap and fuse	8.315	0.665
Lumber, etc.	1.142	0.091
Engineering and superintendence	3.031	0.242
Total excavation	$67.259	$5.379
Total lighting tunnel	$ 2.224	$0.177
Total blacksmithing	$ 2.927	$0.234
Grand total	$84.927	$6.791

The very high cost of the drilling is shown by the following cost per lin. ft. of drill hole:

	Per lin. ft.
Compressor plant ($12.52 per lin. ft. tunnel)	$0.41
Drillers and helpers	0.22
Total	$0.63

Tunnels Nos. 4 and 5.—These tunnels were driven by contract, and hand drills were used entirely. See Table II for time data as to these tunnels, and Table I for "overbreak" data.

The advantage of doing this work by contract is well shown by the following costs, which were the costs to the railway company at contract prices.

COST OF TUNNEL NO. 4 (404 LIN. FT.).

	Total.	Per lin. ft.	Per cu. yd.
2,078 cu. yds. tunnel excavation, at $4.50 per cu. yd.	$ 9,351.00	......	......
972.6 cu. yds. tunnel excavation, at $5	4,863.00	......	......
1,403.5 cu. yds. tunnel excavation, at $4.75	7,094.12	......	......
4,544.1 cu. yds. tunnel excavation	$21,308.12	$51.47	$4.497
Use of 2 cars 160 days, at $1.00	160.00	.38	.034
Horses for cars	70.00	.17	.015
Engineering	670.00	1.62	.141
Superintendence	392.46	.95	.083
Total	$22,600.58	$54.59	$4.770

COST OF TUNNEL NO. 5 (304 LIN. FT.).

	Total.	Per lin. ft.	Per cu. yd.
3,726 cu. yds. tunnel excavation, at $4.50	$16,767.00	$55.15	$4.50
Use of two cars 136 days, at $1 per day	136.00	0.45	.04
Engineering	530.00	1.74	.14
Superintendence	389.60	1.28	.10
Total cost	$17,822.60	$58.62	$4.78

It will be seen that the tunnels driven by company forces cost 50% more than the tunnels driven by contract.

Cost of the New Raton Tunnel.*—Mr. Joseph Weidel, Asst. Engr., A., T. & S. F. Ry., gives the following:

**Engineering-Contracting*, May 3, 1909.

During the latter seventies of the past century, when the Santa Fe Railway was built westward and southward through Colorado and New Mexico, a tunnel was found to be necessary in crossing the divide of the Raton Range, a spur of mountains projecting eastward from the Taos Range in southern Colorado. This tunnel was built during the years of 1878 and 1879, and while it was under construction a switch back was used in crossing the range. Its length is 2,037 ft., and it is on an ascending grade of 2% from the east; the summit being at the west portal. The grades approaching the tunnel, from either end, are 184.8 ft. per mile. The tunnel is 18½ ft. high above top of rail and has a clear width of 14 ft. About 50% of the tunnel is lined with timbers.

This original tunnel had been in constant use for about 29 years when the increase in traffic, size of rolling stock, and loads, and the necessity of extensive repairs forced the company to build a new tunnel. The new tunnel occupies a site adjacent to the old one and at the east portal the two are only 40 ft. apart, center to center. At the east portal the subgrade of the new tunnel is about 12 ft. lower than the subgrade of the old tunnel. The new tunnel is on an ascending grade of 0.50% from the east; the summit being at the west portal.

The new tunnel is 2,786 ft. long, 17 ft. wide at spring line, and 24 ft. high above top of rail and is lined throughout with a concrete wall of an average thickness of 24 ins. There are two shafts approximately 6 x 10 ft. in the clear. One of these shafts is 686 ft. from the east portal and the other 1,100 ft. from the west portal.

The contract for the construction of the tunnel was awarded to The Lantry Contracting Co., a Kansas corporation, organized for this particular purpose. The papers were signed on April 5, 1907, and stipulated that the tunnel was to be completed, ready for track laying, by March 1, 1908. There was a penalty and premium clause in the contract of $100 per day for every day's variation from the stipulated time of completion.

In what follows, it must be borne in mind that the contractor had not hitherto been in the business of tunnel building and he consequently found himself without a suitable working plant or organization at the time the contract was signed.

Mr. Charles E. Higbee, of Denver, Colo., was engaged as Superintendent of Tunnel Excavation and Mr. S. A. Maley, of Kansas City, Mo., was engaged as Superintendent of Concrete Work. Both of these gentlemen had had wide experience in their respective fields, and it was under their direction that the work was successfully completed.

A central power plant was installed near the west end of the tunnel. The principal items of this central plant were, one battery of two horizontal tubular boilers of 100 hp. and 80 hp., respectively; one Sullivan Straight Line Air Compressor W. B. 2, 20 x 22-in. cylinder; one 90-hp. Armington & Sims steam engine for driving the generators; two 25-kilowatt Bipolar Edison Generators of 125 volts; together with pumps, tanks, steam and water pipes

and such other appliances as are needed in an up-to-date power house.

A secondary steam plant was located on top of the mountain for the purpose of supplying power for operating the hoists at the shafts. A 100-hp. boiler was installed and the steam was carried in pipes laid on the surface of the ground, from the boiler to the hoist, for a distance of 500 ft. each way.

From the central power plant at Lynn a 4-in. air line was laid along the surface of the ground, over the top of the mountain, to the Wootton portal. At the Lynn portal, as well as each of the shafts, 2-in. tees were inserted, from whence the air was carried down into the headings and shafts by 2-in. pipes.

The drilling machinery consisted of 10 Sullivan piston and 10 Jeffrey rotary power drills. For ventilating, 2 No. 4½ Baker's rotary blowers were secured. These were operated by 2 7½-hp. motors of 230 volts and 28½ amperes. This outfit was moved from place to place as needed. The cages in the shafts were operated by hoisting engines, using either compressed air or steam.

For excavating the bench, a No. 20 Marion steam shovel was used. This shovel was operated by compressed air from the central power plant. Three dinky engines kept the shovel supplied with cars. Ten 3-cu. yd. dump cars were needed to supply the shovel, 5 in a train.

The rock crushing and concrete mixing plant consisted of 1 Ajax boiler, an engine mounted on wheels, 1 Simmons No. 10 rock crusher, 1 ⅝-cu. yd. concrete mixer of the Ransome type, 10 1½-cu. yd. dump cars and an incline for hoisting the loaded cars from the tunnel grade onto the working platform at the spring line.

There was also constructed an electric light and power line over the mountain for supplying light and power to the camps and tunnel. A telephone system was also installed.

The grading outfit was of the usual kind.

Owing to the lack of water on top of the mountain the company shipped in four tank cars full every 24 hrs., approximately 40,000 gals. being required for all purposes each day.

On April 25, 1907, ground was broken for the power plant at Lynn. While the camp and power plant were in course of construction work on excavating the approaches at Wootton and Lynn was in progress. On April 3 work was begun excavating the shafts. The drilling was done by hand and the excavated material was hoisted by animal power. These shafts were dug about 8 x 12 ft. in the clear and were 109 and 115 ft. deep, respectively, measured from the crown of arch in tunnel. The material penetrated was soft sandstone, hard shale and some coal.

By May 9, when the power plant was ready for service, the excavation of the shafts had been practically completed, all of the work having been done by hand and animal power. For the benefit of those who may have occasion to construct shafts under similar

conditions, I submit the following table, which shows the cost of excavating Shaft No. 1:

Foreman, at $4.50	$ 375.25
Shaft men, at $3	1,792.50
Nippers, at $2	32.00
Timber men, at $3.50	56.00
Teams, at $2.50	132.50
Teamsters, at $2	96.00
327 cu. yds. excavation, at	$2,484.25

The cost per cubic yard of excavation was, then, as follows:

	Per cu. yd.
Labor	$7.60
Explosives	.75
Supervision	.65
Total	$9.00

It may be stated that this includes the placing of approximately 20,000 ft. B. M. of timber lining.

On May 9 the actual work of tunnel excavation was begun by shooting the first round of holes in heading No. 6 at the Lynn portal. On May 24 heading No. 5 was started and on May 28 heading No. 1

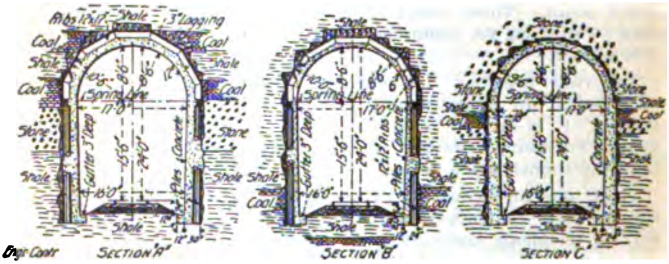


Fig. 4.—Cross-Sections of Tunnel.

was started. On July 9 headings No. 5 and No. 6 met at Station 7 + 12, Lynn end, and on same date headings Nos. 2, 3 and 4 were started. Headings Nos. 1 and 2 met on Aug. 8 at Station 8 + 10, Wootton end. Headings Nos. 3 and 4 met on Sept. 8 at Station 2 + 00, Wootton end, thus completing a hole through the mountain 2,786 ft. long in 122 days from time of beginning.

In taking out the headings it was found that from 12 to 18 holes were necessary to cover the face in a satisfactory manner. The center set of holes was pointed so as to remove a wedge of rock; other holes were then pointed straight ahead. Those at the sides, top and bottom were pointed slightly outward. The average depth of these holes was 8 ft. and the diameter 2½ ins. Sullivan piston and Jeffrey rotary drills, the former mounted on tripods and columns and the latter on the usual frames, both operated by compressed air at 90 lbs. pressure, were used.

As soon as the drilling was finished the holes were cleaned by blowing compressed air into them. They were then charged with dynamite, which was exploded by fuse. Fuses instead of electric exploders were used because of the former permit of timing each shot in such a way as to give the best results from the explosives used. For instance, the central set of holes is fired first, removing a wedge so that the succeeding shots will have two free faces toward which they can break the rock. The "muckers" at the bottom are fired last. Their function is to throw back the debris so that the drillers will be delayed as little as possible before they can proceed with the next set of holes.

The shots were generally fired just before meal time. Immediately after they had been fired, compressd air was permitted to escape into the headings and the ventilating fans were started. It was thus possible to clear the headings of gases so that they could be entered after the meal hour without loss of time. Before firing the shots, sheets of boiler iron were spread on the ground just in front of the holes to facilitate the handling of debris after blasting.

When the workmen returned from their meals the headings had usually been cleared of gases and fumes and the drillers and their helpers would enter and proceed to shovel back any rock that was found to obstruct the working front. As soon as this was done, they proceeded to drill a new set of holes for the next blast. The debris was loaded by from 6 to 10 laborers onto cars of 1½ cu. yds. and ⅝ cu. yd. capacity. The former were used in the headings No. 1 and No. 6, while the latter were used in headings Nos. 2, 3, 4 and 5. The former were pulled by animal power to the portals and the latter were propelled by man power to the shafts. From the portals the 1½ cu. yd. cars ran by gravity to the waste bank, the empties being brought back by horses or mules. The smaller cars at the shafts were raised to the surface by hoisting engines operating cages.

The following is a statement of the cost of excavating heading No. 6:

	Rate.	Total.
Machine foremen	$4.50	$ 495.00
Machine men	4.00	1,196.00
Machine helpers	3.50	1,046.00
Nippers	2.50	507.50
Muck foremen	3.50	387.00
Laborers	2.25	2,975.50
Teams	2.50	315.00
2,897 cu. yds. material excavated...		$6,922.00

The cost per cubic yard for excavation was as follows:

	Per cu. yd.
Field labor	$2.39
Labor operating power plant	0.31
Labor in camp and supervision	0.88
Powder, fuse and caps	0.55
Coal	0.30
Depreciation	0.65
Total	$5.08

A summary of the total and unit costs of all 6 headings is given below:

No.	Length. Ft.	Cu. yds.	Total cost.	Cost. per cu. yd.
1	476	3,165	$17,534.10	$5.54
2	210	1,026	5,550.56	5.41
3	400	1,845	8,320.95	4.51
4	600	2,334	13,233.78	5.67
5	312	1,564	9,274.52	5.93
6	788	2,897	14,716.76	5.08

The material penetrated in heading No. 1 was soft sandstone, while the other headings were mixed sandstone, coal and shale. The most rapid progress was made in heading No. 6, where there was no timber lining to contend with. The average daily progress in this heading was 12½ ft., while for the last nine days the daily average was 17 ft. This, of course, means per 24 hrs. About 55% of the headings were taken out through the shafts.

In moving the bench, holes were drilled vertically about 7 ft. apart. These were shot as in open cut work. The muck was loaded by a No. 20 Marion steam shovel, operated by compressed air. Ten 3-cu. yd. dump cars were used, five in a train. These trains were operated by three dinky engines, one switching at the shovel, one taking the excavated material to the waste dump and one in reserve.

Following is the steam shovel monthly progress.

July	50 ft.	October	355 ft.
August	420 ft.	November	565 ft.
September	540 ft.	December	500 ft.

About 88% of the bench was removed by steam shovel and 12% by hand. If we take into account the entire tunnel excavation, 25% came out through the shafts and 75% through the portals.

The steam shovel began work on July 29 and finished on Dec. 23, a period of 148 days. Below follows a table showing the cost of removing 29,417 cu. yds. of bench excavation by steam shovel:

	Rate.	Total.
Foremen	$4.50	$ 1,300.50
Steam shovel engineer	6.50	1,839.50
Crane men	3.50	897.00
Dinky engineers	3.50	1,791.00
Machine men	4.00	3,604.00
Machine helpers	3.50	3,244.50
Pit men	3.00	5,793.00
Laborers	2.00	6,151.75
29,417 cu. yds.		$24,621.25

The cost per cubic yard was as follows:

	Per cu. yd.
Field labor	$0.88
Labor operating power plant	0.09
Camp labor and supervision	0.26
Powder, fuse and caps	0.17
Coal	0.09
Depreciation	0.19
Total	$1.68

In excavating the tunnel no unusual difficulties were encountered. There was very little water to contend with and the material penetrated was sandstone, shale and coal. About two-thirds of the entire tunnel had to be temporarily lined with timbers. The work was done in the following manner:

As soon as the headings had advanced sufficiently a gang of drillers was set to work enlarging the section to the full semi-circle required. Sills consisting of 12 x 12-in. timbers were bedded at the spring line on each side of tunnel, so that the outer face was a uniform distance of 6 or 12 ins. from the face of the concrete. Engineers gave grade and centers for these and in placing them they were set 4 ins. higher than the theoretical requirements. This was done to allow for subsequent settlement during the excavation of the bench. As soon as the sills were bedded to proper grade, the segments, six in number, were placed. These were made of 10 x 12-in. pieces, or an equivalent section of 3 x 12-in. or 4 x 12-in., was built up. The sill, by the way, was also built up of 3 x 12 or 4 x 12-in. pieces, set edgewise. The segments were spaced 3 ft. on centers. Over the segments 3-in. lagging was placed, this having previously been cut into 3-ft. lengths by means of a circular saw. As soon as the lagging was placed, the void spaces between the lagging and the roof of the excavation were packed solid with stones of various sizes. As fast as the bench was excavated by the steam shovel, it was of course necessary to support the sills at spring line. In this case ordinary piles about 12 ins. in diameter were used. These were spaced variously from 3 to 6 ft. apart, according to the load to be supported. Where the loads were light it was found that short stulls from 4 to 6 ft. long made of 8 x 8-in. stuff answered very well for supporting the roof timbering. In such cases, horizontal struts had to be inserted to prevent the timbers from kicking in at spring line.

The work of enlarging the section, the placing of timbers and the back filling was done by the same set of men. Owing to this circumstance the records of cost data are somewhat less satisfactory in this case than in other portions of the work. Of these three items the records for the cost of enlarging the tunnel section are quite reliable. By subtracting this cost from the total cost of performing the different classes of work, we have an amount which represents the cost of labor placing the timbers and the cost of labor placing the backfilling.

The cost of enlarging the tunnel section was $2.55 per cu. yd. After repeated trials the cost of placing the timbers was ascertained to be $15.55 per M ft. B. M. By subtracting these two, the cost of enlarging the section and the placing of the timbers, the remainder was assumed to represent the cost of back filling. By this process of reasoning it was found that the cost of placing the backfilling was $1.50 per cu. yd. In the abstract such reasoning may be correct, but practically the writer has little faith in the results. Summing up, then, it may be assumed that the cost of enlarging the section is correctly represented by $2.55 per cu. yd., that the cost of placing the timbers lies between $12 and $18 per M

ft. B. M. and that the cost of placing the backfilling was not ascertained.

While the steam shovel was taking out the bench a gang of men was excavating for the footing course of the concrete walls. As soon as portions of these trenches were excavated another gang placed the concrete in the foundation. The mixing was done by hand on sheets of boiler iron placed in front of the trenches. These were moved from place to place as required. However, before any concrete was placed, carpenters erected a sufficient amount of forms to define the neat line of concrete at grade. For setting these forms engineers gave the grade and center points and after the concrete was once placed to this line no further instrumental work was required. All of the foundation concrete, up to the grade line of the tunnel, was placed in the manner indicated above.

For the real work of lining the tunnel the contractor installed a rock crushing and concrete mixing plant in the approach at Lynn, about 200 ft. from the portal. The rock was quarried from the adjacent hill, within 100 ft. of the crusher, which was a No. 10 Simmons. The mixer was of the Ransome type, mixing ⅝ cu. yd. per charge. The crusher was at the top of the approach slope, about 20 ft. above grade. A bin, divided into three compartments, was placed above and to one side of the track in the approach. In the bottom of the compartments were chutes discharging into a measuring hopper. Immediately below the hopper was the mixer and below the mixer and a little to one side stood the cars that received the mixed concrete. The rock was carried from the crusher into the bin by a small chain elevator and the sand was handled in a similar manner. The cement was carried to the bin in sacks. Water was supplied by a 2-in. pipe discharging into the mixer, the amount being controlled by a boy operating a valve. One man operated the measuring apparatus and one attended the mixer.

It will be seen that the entire process of handling the material from the crusher until the concrete reached the cars was mechanical and from the bin to the cars gravity did the work.

The crusher was operated by a stationary engine and the mixer and elevators by independent electric motors. The cars were handled by dinky engines. The sand was shipped from La Junta. The crushing and mixing plant was a complete success from every point of view.

Originally it was the contractor's intention to place all of the concrete lining, above foundation line, off a movable platform at spring line. With this idea in view a standard flat car was secured from the railway company and by means of framework placed upon this car a platform 17 ft. wide and 50 ft. long was supported at the elevation of spring line. This car was carried on a track laid in the center of the tunnel. In order to elevate the concrete cars as they arrived from the mixing plant to spring line, an inclined plane (Fig. 5) with a narrow gage track and mounted on wheels was coupled onto the platform mentioned above. On the flat car was mounted a hoisting engine operated by compressed air. The cars were pushed to the bottom of the incline by dinky engines,

where a cable was hooked onto them and they were then hoisted to the top of platform by means of the hoisting engine. Once on top the concrete was dumped onto the platform and cars returned by gravity to tunnel grade. The concrete was then shoveled into the forms and the idea was that the arch ring would also be turned

Fig. 5.—Method of Handling Concrete for Lining.

at once before advancing the incline and platform to a new position. It was found to be impossible to turn the ring fast enough without delaying the placing of concrete in bench walls. A feature of the forms was to use two 40-lb. bent rails, one on each side and meeting at soffit line, as ribs for supporting lagging for concrete. It is evident that a movable platform will not permit of bracing these

ribs crosswise of the tunnel axis. Owing to this circumstance these ribs lacked stiffness and bulged out considerably when concrete was shoveled into the forms. The long and heavy bent rails were also very difficult to handle. Owing to these drawbacks, this method of placing the concrete was abandoned.

During the short time that the above method of placing the concrete was in vogue it became evident that, in order that work might be carried on without interruption, a platform of considerable length was necessary. It was decided, therefore, to erect a fixed platform at spring line 17 ft. wide and 500 ft. long. Instead of the bent rails for ribs, 6 x 8-in. vertical studding spaced 4 ft. on centers was used. These pieces extended from grade line to spring line and were cross braced about 10 ft. above grade line. On top of these uprights were placed 6 x 10-in. caps, which acted as beams for carrying the loose 2-in. platform floor. The lagging was placed directly behind the vertical studs, to which it was loosely nailed. The old movable platform, mounted on a flat car, and the inclined plane, were then run up to the 500-ft. fixed platform and the concrete was hoisted as before.

While the carpenters were placing the fixed platform, the mixed concrete was brought in and dumped onto sheets of boiler iron at grade line and from there was shoveled into the forms to a height of about 6 ft. above grade. By the time that this height was reached the platform was ready and all concrete above this 6-ft. line was then placed from the fixed platform at spring line. In the center of this platform, for its full length, was a track connecting with the track on the incline. The cars, after they had been hoisted to the platform, were pushed by men to different places and dumped. The cars were then pushed back to the incline and lowered to tunnel grade by gravity, controlled by hoisting engine on movable platform. The concrete was shoveled into the forms until the spring line was reached. As soon as a portion of the bench walls had reached spring line a gang of men erected rail ribs of a 40-lb. section bent into the form of a semi-circle to receive the lagging for turning the arch ring. These rails were generally made in two pieces and were spaced 4 ft. on centers. The lagging was 2-in. stuff and was placed as fast as the placing of concrete required it. The distance from spring line to soffit line is 8½ ft. The placing of concrete in the arch ring for the first 6 ft., did not differ materially from the method of placing it in bench walls, only a little more tamping was necessary to fill the voids. After a point was reached where it was too high to cast in the concrete from the platform at spring line, a small movable platform on wheels, about 8 x 10 ft. and 4 ft. high, was pushed under the arch and the concrete was shoveled from platform at spring line onto this smaller platform and from there into arch ring until only a 3-ft gap remained to be closed.

This was an awkward job and required the closest attention on the part of the foreman to prevent the men from slighting their work. The concrete had to be shoveled in endwise and to facilitate this the length of the lagging for the last 3 ft. of arch ring was cut

down to 3-ft. lengths. The concrete for this was made dryer to prevent it from sloughing back when the tamper was withdrawn.

The temporary timber lining was imbedded in the concrete and had been so placed that at least 6 ins. of concrete was in front of all ribs and sills. In places where the timber had settled or swung out of line, the timbers had settled to such an extent as to weaken the arch, the wooden ribs were replaced by bent rails.

The progress made in lining the tunnel by months was as follows:

	Cu. yds.
October	326
November	1,000
December	985
January	1,986
February	4,173
March	2,931
April	1,025

Besides the tunnel lining proper, the two shafts were also lined with concrete. This was done by force account. At the Wootton end a reinforced concrete portal wall was built and at the Lynn end one of plain concrete was constructed.

The cost per cubic yard of placing concrete, exclusive of the cost of cement, was found from records kept by the assistant engineer to be as follows:

	Fer cu. yd.
Forms and platforms, labor	$0.63
Forms and platforms, lumber	0.54
Crushing and quarrying rock	0.89
Cost of sand (no freight)	0.18
Cost of handling sand at tunnel	0.18
Cost of handling cement at tunnel	0.17
Cost of housing cement at tunnel	0.04
Mixing and transporting concrete	0.41
Placing concrete into forms	0.81
Removing forms and pointing	0.32
Supervision and camp labor	0.66
Labor operating power house	0.20
Coal	0.34
Depreciation of plant	0.65
Nails, oil and candles	0.03
Rental on rails and ties	0.03
Total	$6.08

The lining of the tunnel proper was completed on April 15, while the whole contract was finally completed on June 20, 1908, 444 days after ground was broken.

The cost of the contractor's plant in this case was estimated at $55,000. The outfit was purchased especially for this contract and at the conclusion of the work the contractor offered to sell the plant at 50 cts. on the dollar. This fact accounts for the heavy depreciation charge in the unit costs.

The unit costs given in this article are based upon records kept by the writer as assistant engineer in charge for the railway company. A man was employed to keep this record, who had no other duties to perform, and the results were tabulated every day. From facts known to the writer it is his belief that 10% should be added to these figures to arrive at the actual total cost.

The work was planned and carried on under the direction of Chief Engineer C. A. Morse, of Topeka, Kan., and Engineer F. M. Bisbee of La Junta, Colo. The field force consisted of Assistant Engineer

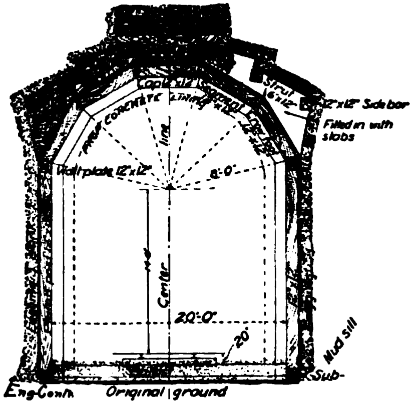


Fig. 6.—Cross-Section of Tunnel.

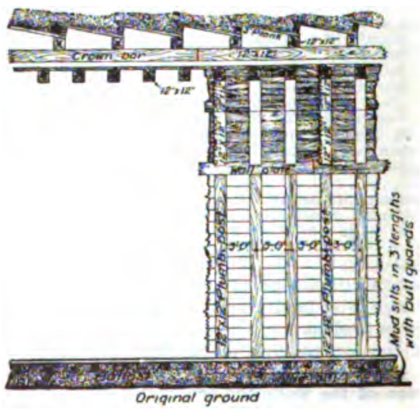


Fig. 7.—Longitudinal Section of Tunnel.

Jos. Weidel with an instrument party and, latterly, during the construction of concrete work, one day and one night inspector.

Cost of Driving a Tunnel in Earth.*—During the past decade a

**Engineering-Contracting,* July 1, 1908.

large number of descriptions have been written of driving tunnels through rock, but only a few tunnels excavated through soft materials have been described in engineering literature, and then only those in which special methods were used, or unusual difficulties encountered. The tunnel described in this article could not be classed as unusual in any respect, nor were any novel methods used on the work, but inasmuch as we are able to give the itemized cost of the tunnel, it may prove of interest.

The tunnel was on the line of one of the large western roads, on the outskirts of a town, crossing under some of the streets, but without many houses in that neighborhood. The length of this single-track tunnel was 2,360 ft. It was lined with timber as shown in Figs. 6 and 7. The cross-section was designed to have ultimately a lining of concrete. There were about 15 cu. yds. of excavation to the running foot figured for the cross-section as designed, which meant a total excavation of 35,385 cu. yds., not including any slips or falls.

The material excavated was mostly a glacial deposit or till, there being at one end some cemented gravel that had to be blasted while the other end was mostly sand. Temporary timbers had to be used and some trouble was experienced with the earth slipping, as the method of putting in the timber roof shows.

The work was done by company's forces and the following wages were paid, the working day being 10 hrs.

Resident engineer	$250.00 per mo.
Assistant engineer	125.00 per mo.
Transitman	85.00 per mo.
Draftsman	75.00 per mo.
Rodman	50.00 per mo.
Chainman	40.00 per mo.
Axeman	2.25 per day
Extra chainman	2.25 per day
Superintendent	225.00 per mo.
Accountant	75.00 per mo.
Purchasing agent	70.00 per mo.
Material clerk	70.00 per mo.
Clerk	40.00 per mo.
Cook	45.00 per mo.
Heading foremen	5.00 per day
Bench foremen	4.00 per day
Track foremen	2.50 per day
Foremen	2.50 per day
Miners	3.00 per day
Muckers	2.00 per day
Nippers	2.00 per day
Team and driver	5.00 per day
Horse and driver	3.00 per day
Rail drillers	2.50 per day
Trackmen	2.00 per day
Dumpmen	2.00 per day
Carpenter foreman	3.50 per day
Carpenters	2.50 per day
Blacksmith	3.00 per day
Helper	2.00 per day
Timber inspector	2.50 per day
Timekeeper	2.25 per day
Mortormen	2.75 per day

The following men were used at times and paid the following wages:

Electrician		$100.00 per mo.
Linemen	$2.50 to	2.75 per day
Carshop foreman		3.00 per day
Carshop carpenter		2.50 per day
Machinists	$2.50 to	3.50 per day
Masons		4.00 per day

Engineering and Superintendence.—Under this head is given the cost of superintendence and the engineering work. The superintendence was a cost that would have come under the contractor's item of general expense, if the work had been done by contract. The two items of engineering and superintendence were kept together, but the superintendence was more costly than the engineering, as the resident engineer gave only part of his time to the tunnel work, and even the assistant engineer's salary was not charged in full against the tunnel. The items going to make up this charge were:

Payroll	$4,582.67
Supplies and incidentals	174.81
Board	663.99
Telephone for office	21.30
Light for office	61.16
Engineering and superintendence	$5,544.03

This gives a cost of 16 cts. per cu. yd. of excavation and a cost of $2.35 per lineal ft. of completed tunnel.

Camp and Offices.—A camp was built near the tunnel site for the men to live in, and an office was also established for the superintendent and the engineers. A temporary depot was built, and a freight house to store supplies. Electric lights were used in some of these buildings, and water was also placed in some, being procured from the town.

The total cost of camp was $3,177.93, and, as some of the buildings were sold and the depot was given to the operating department of the road, a credit of $492 was made to this account, making the net cost of the camp $2,685.93. This means a cost per cu. yd. of excavation of 8 cts., and a cost per lin. ft. of tunnel of $1.14. When work is done by contract the item of camp comes under general expense, but, as a contractor usually charges his men a small rental for houses or bunks, there are generally enough credits made to the camp account to balance it.

Plant.—In spite of the length of this tunnel, being such as to class it as a long tunnel, a compressor plant was not used, but an electric motor was installed and used in operating a motor car to haul material from the tunnel. The motor had been used on some other job and had to be repaired. The total charge for motor, supplies, repairs, operation and power was $3,132.29. When the tunnel was finished the motor was sent to another tunnel that was being driven and a credit was made for the motor of $1,606.36, and $360 for power furnished for other purposes, leaving a net charge of $1,165.93. The cost per cu. yd. of excavation was 3 cts.,

while the cost per lin. ft. of tunnel was 49 cts. In contract work this item would be classed under the head of plant.

Tools.—The tools used on the job were small ones for the excavation and timber work, with the exception of the electric locomotives and the cars for hauling earth and timber. The cost of the tools and supplies was $6,520.04. The cost of repairing and maintaining these was:

Labor	$2,684.95
Coal	135.38
Lumber	195.76
Iron	417.64
Total	$3,433.73

This makes a total expenditure for tools of $9,953.77. At the end of the job, a credit was made of $3,929.16 for tools and supplies sent to another job, leaving a net charge for tools of $6,024.61. This charge properly belongs under the item of plant, yet, inasmuch as the depreciation on small tools is much greater than on machinery, it is well to keep a separate account of tools. The cost per cu. yd. for tools was 17 cts., while the cost per lin. ft. of tunnel was $2.55.

Explosives.—A car load of Forcite dynamite was bought for the job, but only a small part of it was used. The strength was 40 per cent, and it cost 12¼ cts per lb. Two 30-hole exploding batteries were bought, and electrical exploders to use with the batteries. The total cost of explosives was:

Dynamite and exploders	$2,638.48
2 batteries	80.00
Wire	40.00
Total	$2,758.48

At the end of the job, the batteries and unused explosives were sent to another piece of work. A credit of $60 was made for the two batteries, and $2,030.29 was credited for the explosives. Consequently there remained a net charge of $668.19 for blasting. This makes a charge of 2 cts. per cu. yd. and 28 cts. per lin. ft. of tunnel.

Tunnel Excavation.—The excavation was done in the usual manner. The heading was excavated and timbered, then widened out and the roof supported in the manner shown in the illustrations, with the addition of temporary props. Then the bench was excavated and the permanent timbering finished. The excavated material was wheeled out of the heading in wheelbarrows, and horses were used in pulling the cars from the bench excavation to the dump, but as the haul became long, the electric locomotives previously referred to were used. Candles were used to give light in the headings, the expense for this being $116.71. Electric wire was strung for the motors and also for lighting purposes. The costs for the hauling has been included in that for plant, but this work for the lighting and the power rented, with the lights, wires, etc., cost $1,191.57, making a total cost of $1,308.28. This makes a

cost of 4 cts. per cu. yd. for lights, and 55 cts. per lin. ft. of tunnel.

Another item of cost was some incidentals on the outside of the tunnel, such as small drains at street crossings, some clearing, a temporary trestle, the blocking up of a warehouse, and other details on which $1,158.27 was spent for materials and labor. For these incidentals the cost per cu. yd. was 3 cts. and the cost per lin. ft. of tunnel was 49 cts.

The expenses for labor and teams was $75,762.10, making a cost per cu. yd. of $2.14 and per lin. ft. of tunnel of $32.12.

Timber Lining.—The total amount of timber used was 2,434,200 ft. B. M., costing $20,223.18. This is exclusive of wedges, cordwood and iron. Cordwood was used for packing, the plans calling for 533 cords, but only 451 cords were bought, the price per cord being $1.50. The deficiency was made up by using old pieces of temporary timbers and scraps. The cost of the cordwood was $658.16. Wedges were made from 2x12 boards, and cost to make from 1¼ to 2 cts. a piece. These were made by contract, about 15,000 being used, costing $2,586.95. The iron and nails used cost $669.79.

The amount of permanent timber called for by the plans was 1,687,200 ft. B. M. The average price paid for this was $8.40 per M. In addition to this 747,000 ft. B. M. were used as temporary timbers and for other purposes. This cost an average price of $8.10 per M. The cost of labor for framing and placing timber, exclusive of the time of the men from the mucking gangs that may have been used temporarily, was $8,615.40. This gives a cost for framing and placing per M. ft. of timber as called for by the plans of $5.10, while the cost per M. for the total amount of timber used was $3.54. Separate record was not kept of placing the cordwood. The total cost of the lining was:

Lumber	$20,223.18
Cord wood	658.16
Wedges	2,586.95
Iron	669.79
Labor	8,615.40
Total	$32,753.48

The cost of each of these items per cu. yd. of excavation was:

	Per cu. yd.
Lumber, at $8.30	$0.57
Cordwood	0.02
Wedges	0.07
Iron	0.02
Labor	0.24
Total	$0.92

The cost of lining per lin. ft. of tunnel was:

	Per lin. ft.
Lumber, at $8.30	$8.53
Cordwood	0.28
Wedges	1.09
Iron	0.28
Labor	3.65
Total	$13.83

Personal Injury.—No one was killed in building this tunnel; however, a number of men were hurt, but none seriously. Various expenses were incurred on account of those injured, there having been paid out $2,170.45, making a cost per cu. yd. of 6 cts., and per lin. ft. of tunnel of 92 cts.

Summary of Cost.—The total cost of the entire work was:

Engineering and superintendence	$ 5,544.03
Camp	2,685.93
Personal injury	2,170.45
Plant	1,165.93
Tools	6,024.61
Expenses	668.19
Tunnel Excavation:	
Light	1,308.28
Incidentals	1,158.27
Labor	75,762.10
Timber Lining:	
Lumber	20,223.18
Cord wood	658.16
Wedges	2,586.95
Iron	669.70
Labor	8,615.40
Total	$129,241.27

The cost per cu. yd. for each of these items was:

	Per cu. yd.
Engineering and superintendence	$0.16
Camp	0.08
Personal injury	0.06
Plant	0.03
Tools	0.17
Explosives	0.02
Tunnel Excavation:	
Light	0.04
Incidentals	0.03
Labor	2.14
Timber Lining:	
Lumber	0.57
Cord wood	0.02
Wedges	0.07
Iron	0.02
Labor	0.24
Total	$3.65

The cost per lin. ft. of tunnel for each item was:

	Per lin. ft.
Engineering and superintendence	$ 2.35
Camp	1.14
Personal injury	0.92
Plant	0.49
Tools	2.55
Explosives	0.28
Tunnel Excavation:	
Light	0.55
Incidentals	0.49
Labor	32.12
Timber Lining:	
Lumber	8.53
Cord wood	0.28
Wedges	1.09
Iron	0.28
Labor	3.65
Total	$54.82

The total payroll on the job amounted to about $90,000 and it will be noticed that the amount paid out for personal injuries was $2,170.45. If liability insurance had been taken out for this job the rate would have been less than 2 per cent, hence money would have been saved. It is always well on construction work to carry this kind of insurance.

No record was kept of the slips and slides that occurred in the tunnel, but some must have occurred as glacial drift is apt to be treacherous material to tunnel through, and this must not have been an exception to the rule, as the large amount of temporary timber used bears witness.

Considering the high wages paid, and the fact that the work was done by day labor, the cost is not excessive, but no doubt timber was wasted, yet the prompt use of temporary timbers in some places may have saved money when heavy slips were threatened.

The engineering and superintendence together were less than 5 per cent of the total cost. This would mean that the engineering expense did not exceed 2 per cent, and the cost of locating the work is included in this. The item of general expense, as a contractor would have classified it, including superintendence, camp, and personal injury, was about 6 per cent. This could have been cut down a little by taking liability insurance, and charging rent for the camp. The plant and tool charge was a little more than 5 per cent. The tunnel lining was 25 per cent of the total cost.

The excavation of the heading was commenced in March. Work was started at both ends of the tunnel. During April no work was done inside the tunnel, but in May active operations were commenced and night and day forces were put to work. The headings were finished in August, and the benches cleaned up by the middle of September. Each heading foreman worked from 9 to 10 men, while the bench foremen worked from 15 to 20 men in their gangs. At one end of the tunnel a bench sub-foreman with extra men were used for several months. When work first commenced, the track gangs had from 10 to 15 men in them, there being a track gang for each end of the tunnel; but, as soon as the work was well under way, these gangs were cut down to 6 men each, and at the end only 4 men were kept in a gang. The timber gangs, consisted of a foreman, from 7 to 10 carpenters and a timber inspector. There was a night and day gang of carpenters from May to September.

Cost of Lining the Mullan Tunnel.—The tunnel is 3,850 ft. long, 20 miles west of Helena on the Northern Pacific Ry. Falls of rock and fires in the tunnel had caused numerous delays. The original timbering consisted of sets 4 ft. c. to c. of 12 x 12-in. timbers, with 4-in. lagging. The size was 16 x 20 ft. in the clear.

Concrete side walls (30-in.) and four-ring brick arch were built in place of the old timbering. A 7-ft. section was first prepared by removing one post and supporting the arch by struts. Two temporary posts were sent up and fastened by hook bolts; and a lagging was placed back cf them to make forms to hold the

concrete. Several of these 7-ft. sections were prepared at a time, each two being separated by a 5-ft. section of the old timbering.

The mortar car delivered Portland cement mortar (1 to 3) through a chute, making an 8-in. layer of mortar into which broken stone was shoveled until all the mortar was taken up by the stone voids. In 10 to 14 days the walls were hard enough to support the arches which were then allowed to rest on the walls, and the posts of the remaining 5-ft. sections were removed, and concrete placed as before. About 4 parts of mortar were used to 5 parts of broken stone, which is a very rich concrete. The average progress per working day was 30 ft. of side wall, or 45 cu. yds. From 3 to 9 ft. of brick arch were put in at a time, depending upon the nature of the ground. To remove the old timber arch, one of the segments was partly sawed through, and a small charge of dynamite exploded in it; the debris being caught on a platform car, from which it was removed to another car and conveyed away. The center was then placed, and the cement car used to mix mortar on. Brick were 2½ x 2½ x 9 ins., four ringings, making a 20-ft. arch and giving 1.62 cu. yds. per lin. ft. of tunnel. The bricks were laid in rowlock bond. Two gangs of 3 bricklayers and 6 helpers each, laid 12 lin. ft., or 19.4 cu. yds., of brick arch per day.

The foregoing description of the work is given by Mr. H. C. Relf. The following data were published in *Engineering-Contracting*, July 17, 1907.

For most of the distance it was lined with concrete side walls and concrete arch, but for part of the distance a brick arch was used instead of concrete. The brick was used only where it was necessary to support the roof by timbering, for wherever the roof would stand without props the concrete was used on account of its much greater cheapness.

The concrete side walls were 14 ft. high and had an average thickness of 2½ ft. Therefore each side wall averaged nearly 1.3 cu. yds. per lin. ft., and the two walls averaged 2.59 cu. yds. per lin. ft. of tunnel. The concrete was mixed 1:3:5, being, we believe, unnecessarily rich in cement. The average amount of concrete placed in the walls per day was 50 cu. yds.

COST OF SIDE WALLS.

	Per cu. yd.
Materials:	
1.33 bbl. cement, at $2.00	$2.66
0.5 cu. yd. sand, at $0.18	0.09
0.75 cu. yd. stone, at $0.55	0.41
Total	$3.16
Labor on Concrete:	
0.01 day foreman, at $5.00	$0.05
0.03 day foreman, at $3.00	0.09
0.03 day engineman, at $3.00	0.09
0.35 day laborer, at $1.75	0.61
0.42 Total	$0.84

Labor, Removing Timber, Building Forms, Excavating Etc.:

0.02 day foreman, at $5.00	$0.10
0.05 day foreman, at $3.00	0.15
0.40 day laborer, at $1.75	0.70
0.47 Total	$0.95

Miscellaneous:

0.02 day engineer and superintendent, at $5	$0.10
Falsework and forms, timber and iron	0.07
Tools, light, etc.	0.10
Interest and depreciation of $1,800 plant at 20% per annum	0.09
Train service, 0.03 day work train, at $25	0.75

Summary Concrete Side Walls:

Materials	$3.16
Labor on concrete	0.84
Labor removing timber, etc.	0.95
Train service	0.75
Miscellaneous	0.34
Total	$6.04

In the two side walls there were 2.59 cu. yds. of concrete per lin. ft. of tunnel, hence the cost of the side walls was $6.04 × 2.59 = $15.64 per lin. ft. of tunnel.

The concrete arch varied in thickness, averaging from 14 to 20 ins. at the springing line to 8 to 14 ins. at the crown. The arch averaged 1.2 cu. yds. per lin. ft. of tunnel. About 20 cu. yds. of arch were placed per day. The arch concrete was mixed 1:3:5 and the cost was as follows:

COST OF CONCRETE ARCH.

Materials:		Per cu. yd.
1.36 bbls. cement, $2.00		$2.72
0.05 cu. yd. sand, $0.18		0.09
0.75 cu. yd. stone, $0.55		0.41
Total		$3.22
1.8 cu. yds. dry rock backing, at $0.55		0.99
Labor on Concrete:		
0.02 day foreman, at	$5.00	$0.10
0.12 day foreman, at	3.00	0.36
0.88 day laborer, at	1.75	1.54
1.02 Total	$1.96	$2.00
Labor Placing 1.08 Cu. Yds. Rock Backing:		
0.01 day foreman, at	$5.00	$0.05
0.51 day foreman, at	$3.00	0.15
0.55 day laborer, at	1.75	0.96
0.61 Total	$1.90	$1.16
Labor Removing Timbers, Removing Forms, Excavation, Etc.:		
0.02 days foreman, at	$5.00	$0.10
0.04 days foreman, at	3.00	0.12
0.06 day carpenter, at	2.50	0.15
0.40 day laborer, at	1.75	0.70
0.52 Total	$2.06	$1.07

Train Service:

0.06 day, at $25	$1.50

Miscellaneous:

Engineering and superintendence	$0.07
Falsework, timber and iron	0.13
Tools, light, etc.	0.12
Interest and depreciation, $1,800 plant, 20% per annum	0.09

Summary Concrete Arch:

Concrete materials	$3.22
Dry rock backing (1.8 c. y.)	0.99
Labor and concrete	2.00
Labor placing 1.8 cu. yds. rock backing	1.16
Labor removing timber, etc.	1.07
Train service hauling materials	1.50
Engineering and superintendence	0.07
Falsework, timber and iron	0.13
Tools, light, etc.	0.12
Interest and depreciation plant	0.09
Grand total	$10.35

It will be noted that the "train service" is an item that really should be considered as a part of the cost of the materials, for the cost of the sand and stone is the cost f. o. b. cars at the sand pit and at the quarry, to which should be added the cost of hauling them to the tunnel—to-wit, the "train service."

Summing up, we have the following as the cost per lineal foot for lining this single-track tunnel with concrete:

		Per lin. ft.
2.59 cu. yds. side walls, at	$ 6.04	$15.64
1.20 cu. yds. arch, at	10.33	12.40
3.79 cu. yds. Total	$9.38	$28.04

It should be remembered that the higher cost of the arch concrete is due in large measure to the fact that 1.8 cu. yds. of dry rock packing above the arch is included in the cost of the concrete. Strictly speaking, this dry rock packing should not be charged against the arch concrete, and, segregating it, we have the following:

		Per lin. ft.
2.59 cu. yds. concrete side walls, at	$6.04	$15.64
1.20 cu. yds. concrete arch, at	8.18	9.82
2.16 cu. yds. dry rock, at	0.55	1.19
Labor placing 2.16 cu. yds., at	0.64	1.39
Total		$28.04

This is a much more rational analysis of the cost and a still further reduction in the cost of the arch concrete might be made by prorating the train service item ($1.50 per cu. yd. concrete). At least half of this train service should be charged to the dry rock backing, for there are 1.25 cu. yds. of sand and broken stone to 1.80 cu. yds. of dry rock backing.

The amount of this dry rock backing, or packing, varies greatly in different parts of a tunnel. In the first half of this tunnel it averaged 1.8 cu. yds. per lin. ft., while in the second half it averaged

nearly 2.4 cu. yds. per lin. ft. In a subsequent issue we shall give the cost of lining a tunnel that averaged 1.4 cu. yds. of dry rock packing per lin. ft.

As previously stated, part of this tunnel was arched with brick instead of concrete. About one-third of the tunnel was thus arched with brick, laid 2 to 5 rings thick, and averaging 1.28 cu. yds. per lin. ft. of tunnel.

The average progress was 13 lin. ft. per day. The brick were 2¼x4x8 ins. in size. The cost of the brick arch was as follows:

		Per cu. yd.
Materials:		
500 brick, at	$7.00	$3.50
1.02 bbl. cement, at	2.00	2.04
0.4 cu. yd. sand, at	0.25	0.10
Total		$5.65
1.5 cu. yds. dry rock backing at	$0.55	$0.83
Labor and Masonry:		
0.03 day foreman, at	$5.00	$0.15
0.03 day foreman, at	3.00	0.09
0.32 day masons, at	3.00	0.96
0.65 day laborers, at	1.75	1.14
0.06 day sta. engr., at	3.50	0.21
1.09 days. Total	$2.34	$2.55
Labor Removing Timbers, Moving Centers, Excavating, Etc.:		
0.02 day foreman, at	$5.00	$0.10
0.07 day foreman, at	3.00	0.21
0.07 day carpenter, at	2.50	0.18
0.46 day laborer, at	1.75	0.81
0.62 day. Total	$2.10	$1.30
Labor Placing Rock Backing:		
0.01 day foreman, at	$5.00	$0.05
0.06 day foreman, at	3.00	0.18
0.52 day laborer, at	1.75	0.91
0.59 day. Total	$1.93	$1.14
Train Service:		
0.06 day, at	$25.00	$1.50
Miscellaneous:		
Engineering and superintendence		$0.04
Falsework, timber and iron		0.12
Tools, light, etc.		0.12
Interest and depreciation, $1,800 plant, 20% per annum		0.09
Total		$0.37
Summary of Brick Arch:		
Materials for masonry		$ 5.64
Labor on masonry		2.55
Labor removing timber, etc.		1.30
Train service		1.50
Miscellaneous		0.35
Total		$1124
Dry rock backing		0.83
Labor placing rock backing		1.14
Grand total		$13.21

The cost per lin. ft. of tunnel for lining with a brick arch resting on concrete side walls was as follows:

	Per lin. ft.
2.50 cu. yds. concrete side walls at $6.04	$15.64
1.28 cu. yds. brick arch at $11.24	14.39
1.92 cu. yds. rock backing at $0.55	1.06
Labor placing 1.92 cu. yd. rock backing at $0.76	1.46
Total	$32.55

The previous remarks about train service apply in this case also.

Not much has ever been published on the cost of tunnel lining. Several examples of such cost are given in Gillette's "Rock Excavation," but the costs there given are considerably higher than those above recorded. In making comparisons, however, the reader is cautioned to compare the cost per cubic yard of lining as well as the cost per lineal foot of tunnel. The character of the ground and the opinion of the engineer influence the thickness of the lining used, so that one tunnel may contain twice as many cubic yards per lineal foot as another tunnel of equal size.

Masonry lining put in at the time of construction is obviously cheaper than lining put in to replace an old timber lining. Not only does the passage of trains delay work, but the cost of removing the old timber lining is no small item itself. The work above described involved the removal of an old timber lining, yet it was done at a very low cost, particularly when one considers that it was done by company forces and not by contract.

Cost of Lining a 1,000 Ft. Railway Tunnel.*—This tunnel was lined with concrete side walls and a brick arch, the length of the lining being about 1,000 lin. ft. The two concrete side walls averaged 3.2 cu. yds. per lin. ft. of tunnel, and the cost was as follows, per cu. yd.

	Per cu yd.
1.1 bbl. cement at $2.00	$2.20
0.9 cu. yd. stone at $0.60	0.54
0.5 cu. yd. sand at $0.12	0.06
Tools	0.04
Light	0.01
Falsework, timber and iron	0.07
Labor excavating for and building side walls	1.75
Engineer and superintendence	0.15
Work train service	0.90
Total	$5.75

Laborers received $2.00 a day on the concrete work. We are unable to give the cost of the labor in as much detail as was given in our issue of July 17, but the total cost per cubic yard is nearly the same in both cases. The cost of the sand was merely the cost of loading. Work train service (90 cts. per cu. yd. of concrete) covers the cost of hauling sand and broken stone.

There were four rings of brick in the arch which averaged 1.8 cu. yds. per lin. ft. of tunnel. The brick measures 2⅛x3⅞x8 ins. The cost of the brick arch was as follows per cu. yd.

**Engineering-Contracting*, Aug. 14, 1907.

Materials.	Per cu.yd.
1.1 bbls. cement at $2.00	$2.20
480 brick at $7.00	3.36
0.4 cu. yds. sand at $0.50	0.20
Total	$5.76
Labor: Excavating and Preparing for Arching Moving Centers.	
0.03 day foreman at $4.00	$0.12
0.06 day foreman at $3.50	0.21
0.01 day timekeeper at $2.50	0.03
0.02 day blacksmith at $2.50	0.05
0.27 day laborer at $2.00	0.54
0.39 day at $2.44	$0.95
Mixing Mortar and Building Brick Arch.	
0.03 day foreman at $4.00	$0.12
0.06 day foreman at $3.50	0.21
0.01 day timekeeper at $2.50	0.03
0.05 day brick mason at $3.50	0.18
0.23 day brick mason at $3.00	0.69
0.35 day laborer at $2.00	0.70
0.73 day at $2.65	$1.93
Quarrying Rock for and Filling Over Arch.	
0.07 day at $2.15	$0.28
Engineering and superintendence	0.16
Work train service	0.56
Falsework, timber and iron	0.07
Tools, light, etc.	0.05
Summary of Brick Arch.	
Materials	$5.76
Labor, excavating, etc.	0.95
Labor, mix mortar, etc.	1.93
Quarrying rock and filling over arch	0.15
Engineering and superintendence	0.16
Work train service	0.56
False work	0.07
Tools, light, etc.	0.05
Total	$9.63

Summary of Tunnel Lining.	Per lin. ft.
3.2 cu. yd. concrete sidewalls at $5.72	$18.30
1.8 cu. yd. brick arch at $9.63	17.33
Total	$35.63

The two portals were of concrete and each contained 250 cu. yds. The average cost of each portal was as follows:

	Per portal.
275 bbls. cement at $2.00	$ 550
225 cu. yds. rock at $0.60	135
110 cu. yds. sand at $0.12	13
Work train service	150
Lumber for forms	70
Labor, erecting and removing forms	140
Labor excavating for and building portals	500
Engineering and superintendence	50
Total	$1,608

This is equivalent to $6.45 per cu. yd. of concrete in the portals. The cost of two portals, $3,216, distributed over a tunnel 1,000 ft. long, adds $3.22 per lin. ft. to the cost of the masonry lining.

Cost of a Brick and Stone Lining.—(The data on tunnels above described should be consulted for data on concrete lining.) Drinker gives the following data on the lining or Carr's Tunnel (825 ft.) on the Pennsylvania R. R. in 1868-1869. Brickwork: 609,000 brick in the arch (5 per cent broken and lost); 10.44 bushels of neat cement (no sand used in the mortar) laid 1,000 bricks, the mortar forming 30 per cent of the brick masonry; the arch was 25 ins. thick, 24½-ft. span and 9-ft. rise:

	Cost per M.
Bricks f. o. b.	$ 8.80
Loss in handling	.51
Unloading and delivering	1.92
Laying	5.84
Cement	5.10
Total	$22.17

Bricklayers received 40 cts. per hr.; helpers, 17½ cts. per hr.; carpenters, 27½ cts. per hr.; laborers, 17 cts. per hr.

Stonework: 1,730 perches (25 cu. ft.) of rough masonry for side walls, presumably sandstone; 187 perches of ring stone; 25 perches wasted in dressing. The bench walls were 4 ft. wide at the bottom, 3 ft. at the top and 13 ft. high:

	Cost per perch.
Quarrying (1,730 perches)	$ 4.80
Cutting (1,730 perches)	4.36
Hauling (1,942 perches)	1.06
Handling and laying (1,917 perches)	2.80
Cement, 1.65 bu. per perch (8 1/6 per cent of the Masonry)	.81
Total	$13.83

Stone cutters and masons received 35 cts. per hr.; quarrymen, 17½ cts.; laborers, 17 cts. The stone side walls were laid in 8 courses averaging 2 ft. thick each; hence there were 52,800 sq. ft. of beds cut; and estimating each stone 3 ft. long and dressed for 1½ ft. back of the face on joints, there were 14,300 sq. ft. of joints; making a total of 67,100 sq. ft. of cutting which cost 11.2 cts. per sq. ft. This is said to have been too high a cost, if the measurements were correct.

Arch centering cost $1,400, to which was added $600 for moving the centering forward from time to time; making $2.40 per lin. ft. of tunnel, to which must be added $0.70 per ft. for scaffolding.

Weights and Price of Rails.—Steel rails are sold by the ton of 2.240 lbs. The standard price for many years past has been $28 per ton at the mills, Pittsburg, Chicago, etc. Railways have charged one another ½ ct. per ton-mile freight on rails.

The number of tons of rails per mile of single track is exactly $\frac{11}{7}$ of the weight of the rail in pounds per yard of length. Thus a track laid with 80-lb. rails will require $\frac{11}{7} \times 80 = 125.5 +$ tons per mile of single track.

Prices of Rails Since 1876.*—We publish below the price of steel rails at Pittsburg for the years 1876 to 1907 inclusive. We also include the price of iron rails from 1876 to 1882. After the last named date iron rails were seldom laid.

It will be noted that since 1888 the price of rails has never varied much from the present price, except in the years 1897 and 1898.

PRICE OF RAILS AT PITTSBURGH, PA.
(Statistical abstracts of U. S. Dept. Commerce and Labor, 1905, page 539.)
(Ton equals 2,240 lbs.)

Year.	Price per ton, steel rails.	Price per ton iron rails.
1876	$59.25	$41.25
1877	45.58	35.25
1878	42.21	33.75
1879	48.21	41.25
1880	67.52	49.25
1881	61.08	47.13
1882	48.50	45.50
1883	37.50	....
1884	30.75	....
1885	28.52	....
1886	34.52	....
1887	37.08	....
1888	29.83	....
1889	29.25	....
1890	31.78	....
1891	29.92	....
1892	30.00	....
1893	28.12	....
1894	24.00	....
1895	24.33	....
1896	28.00	....
1897	18.75	....
1898	17.62	....
1899	28.12	....
1900	32.29	....
1901	27.33	....
1902 to 1907	28.00	....

The Cost of Track Laying.†—Contracts for track laying on new railway construction are not at all uniform as to specified methods of payment, largely because of varying practice as to the time and method of ballasting. If the ballast is not placed at the time of track laying, it is customary to divide the payment for track work in two parts—(1) track laying and (2) surfacing track.

Track laying involves the unloading of the ties and rails from the cars, trimming the earth to true grade to receive the ties, delivering and placing the ties and rails thereon, curving the rails and joining them.

The railway company usually stands the cost of loading the ties, rails, etc., at the material yard and the transportation to the site of track laying work. This expense is charged upon the railway company's books as "train service."

**Engineering Contracting*, July 8, 1908.

†*Engineering-Contracting*, Oct. 7, 1908.

Surfacing track consists in shoveling earth in between the ties, aligning the track and tamping. Where suitable material for filling between the ties is not at hand, it is hauled in on cars at the expense of the railway company, and the contractor loads and unloads these cars at a separate unit price agreed upon. Such material if hauled in is usually gravel, and is called ballast.

On the Northern Pacific Railway the contract prices for track laying and surfacing have been quite constant for the last 30 years, being about $250 per mile for track laying and $200 per mile for surfacing. The engineer's preliminary estimates of the cost of "train service" have usually been about $100 a mile, but the actual cost has ranged from $75 to $150 a mile. Summarizing we have:

	Per mile.
Tracking laying (contract price)	$250
Surfacing (contract price)	200
Train service (including loading)	125
Total	$575

Of course the length of all permanent siding is included in arriving at the mileage.

In addition to this item of "train service" there is the cost of transporting workmen to the site of the work, for, under most contracts, the railway company agrees to carry the contractor's workmen free over its own lines. The railway also frequently agrees to carry the contractor's plant, including animals, free for some prescribed distance. This cost of transporting men and plant has seldom exceeded $25 per mile of track. This brings the total cost up to about $600 a mile. An allowance greater than this is usually an error on the side of liberality.

The item that we have called "train service" is commonly underestimated by engineers who have not had access to the books of railway companies, so that an analysis of items that go to make up this cost of train service will prove of decided value to the majority of railway engineers. Such an analysis follows:

	Per day.
1 engineman	$ 3.60
1 fireman	2.00
1 conductor	3.00
2 brakemen at $2	4.00
1 engine	7.50
14 flat cars at 35 cts.	4.90
4 tons coal at $3	12.00
Oil and waste	0.75
Total	$37.75

In round numbers we may call it $40 a day for a train and train crew.

It must be remembered that the train crew is paid by the month and not by the day. Hence the average number of miles of track laid per month should be divided by the total number of working

days in the month and not by the number of days actually worked in arriving at an average daily mileage for track laying to be divided into the cost of train service.

It must also be remembered that the number of trains required can not be determined by the *average* haul of materials, but by the *longest* haul from the material yards to the front.

Usually three trains are needed in building a long line, where the track laying gang is large enough to lay 2 miles of track a day when working. Due to spells of bad weather, delays occasioned by non-completion of bridges, etc., the monthly average will not be more than 40 miles, or 1.5 miles per working day. Hence 3 trains at $40 equals $120, which divided by 1.5 miles gives $80 per mile for train service.

To this must be added the cost of unloading rails and ties in the material yard. The rails and fastenings weigh about 120 tons per mile, and the ties weigh about 200 tons per mile of track. Practically all the steel has to be unloaded and loaded again, but usually the ties are delivered with such regularity that only a small portion of them needs to be stored. Contract prices for loading rails at 10 cts. a ton are not uncommon, although the price frequently runs as high as 25 cts. By common forces, materials should be unloaded and reloaded for 25 cts. a ton. Hence, if all the track materials were thus handled, the yard expense would not exceed $80 per mile of track. Under ordinary conditions not more than half the materials are thus handled in the yard, so that the yard cost averages about $45 per mile of track. Adding this to the item of train service we have the total of $125 per mile of track, as above stated.

Where all the track is to be ballasted at once, the present practice is to include the cost of "surfacing track" as a part of the cost of ballasting.

To indicate how the contract prices run under such conditions, we may cite the bids on the Portland & Seattle Ry., in 1906, which were as follows:

Track laying, including loading of track materials but not including unloading in the yard, $300 per mile.

Tie plating (fully tie plated), $75 per mile.

Labor on single tie plates, 1⅝ cts. each.

Labor on switches, $25 each.

Ballast, 27 cts. per cu. yd.

This price is for gravel ballast and includes all the cost of loading and unloading the same and tamping it under the ties, and lining up the track, but does not include the train service nor the wear and tear on the steam shovel which is furnished by the railway company. The train service rarely exceeds 8 cts. per cu. yd. and another 1 ct. will usually cover steam shovel repairs and depreciation. This 9 cts. added to the contract price of 27 cts. gives a total of 36 cts. per cu. yd. of gravel ballast in place. This is a liberal estimate under ordinary conditions.

We give the following as confirming the above given estimate of $150 per mile for "train service," yard work and transportation of men in track laying:

On the Seattle and Montana Ry., built in 1891, the train service, etc., cost $67 per mile of track for 79 miles.

On the Idaho division of the Great Northern Ry. (110 miles long), built in 1892, the train service, etc., cost $125 per mile of track.

On the Cascade division of the Northern Pacific Ry., built in 1884, the cost of train service, etc., was $170 per mile of track. This was a difficult section over the Cascade Mountains. On an easier section the corresponding cost was $150 per mile.

On the Snake River branch of the O. R. & N., built in 1899, the cost of train service, etc., was $154 per mile, to which must be added $18 per mile for the cost of transporting men, etc.

It will be seen from these figures that engineers quite commonly underestimate the total cost of track laying and surfacing. Frequently estimates may be seen that contain no allowance whatever for train service and work at the material yards.

Cost of Tracklaying, M., St. Paul & S. S .M. Ry.—About 263 miles of track were laid in 1892-3 from Valley City across North Dakota. The tracklaying and surfacing were done by the railway company, not by contract. The track was 72-lb. rails laid on 16 ties to the 30-ft. rail. The construction train was made up of 32 cars, the locomotive being in the middle of the train. The next car behind the locomotive was an ordinary flat car loaded with telegraph material; then followed 15 box cars loaded with ties. In front of the locomotive were the following cars, No. 1 being the one farthest front.

No. 1, Pioneer car. This was double deck, containing blacksmith shop, store room, general foreman's office, telegraph office, two sleeping rooms, and three extra berths. In front of the car was a platform carrying extra splice bars, bolts and spikes.

No. 2, store car. This was double deck, and had a store room for provisions and one for clothes, sleeping berths for cooks and a sleeping apartment above.

Nos. 3 and 4, dining and sleeping cars, double deck.

No. 5, kitchen car, single deck.

No. 6, dining and sleeping car, double deck.

No. 7, feed and fuel car, ordinary box car.

No. 8, water car, flat car with a 2,000-gal. tank at each end.

Nos. 9 to 16, flat cars with rails and spikes.

Work commenced at 7 a. m., the teams hauling ties from the five rear cars. The ties were shoved from the car down a tie chute, provided with three rollers, and were loaded into a V-shaped rack on a wagon holding 25 ties. The rails were unloaded onto the ground from both sides of the cars, and the train pulled back out of the way. The rails were loaded onto two "iron cars" and hauled to the end of the track by horses. The iron car gang would "drop" 100 rails (1,500 ft. of track) in half an hour. As soon as a pair was dropped upon the ties, a hook gage was thrown over them, at the forward end, and the horse pulled the car forward 30 ft. Two more

rails were then run out, and so on. The tracklaying force was as follows:

	Per day.
Iron car gang, who dropped rails, 22 men at $2.25	$ 49.50
Strappers, who adjusted and bolted splices, 6 men at $2.00	12.00
Spike peddlers, 2 men at $1.50	3.00
Tie-spacing gang, 12 men at $1.50	18.00
Men lining ties, with rope and stakes, 2 men at $1.75	3.50
Men spacing joint ties, 2 men at $1.75	3.50
Men leveling grade cut by tie wagons, 4 men at $1.50	6.00
Spikers, 16 men at $2.00	32.00
Nippers, holding up end ties for spikers, 8 men at $1.50	12.00
Tracklining gang, 6 men at $1.75	10.50
Teamsters for tie wagons ($35 per mo. and board), 40 men at $2.00	80.00
Men unloading ties from cars, 15 men at $1.75	26.25
Men unloading rails and fastenings from cars, 4 men at $1.75	7.00
Telegraph gang, 8 men at $1.75	14.00
Telegraph operator ($50 per mo.), 1 man at $2.00	2.00
Drivers of iron car horses, 2 men at $1.75	3.50
Blacksmith, 1 man at $2.25	2.25
Night watchman, 1 man at $1.50	1.50
Cooks ($50 per mo.), 2 men at $2.00	4.00
Baker, working nights, 1 man at $2.50	2.50
Waiters, 5 men at $2.00	10.00
Storekeeper, 1 man at $2.50	2.50
Foremen ($65 per mo. each), 5 men at $2.80	14.00
General foreman ($150 per mo.), 1 man at $6.00	6.00
Total	$325.50

Note that the teams of horses are not included, but the drivers of the teams are included in the above. The men were boarded for $3.50 a week, and this was deducted from the wages of all except teamsters.

The average daily wage of these 167 men was $1.95.

The telegraph gang, consisted of 8 men and 1 foreman. The cedar poles were 25 ft. long, spaced 30 to the mile, set 5 ft. in the ground. The wire was stretched from a reel on a small hand wagon pushed by the men.

This force of 167 men and about 90 horses averaged 3 miles of track per day. If we consider horses (not including driver) as costing $1 per day, we have a total daily cost of $415.50, not including the cost of operating two locomotives and trains, which may be rated at $40 each (including wages, fuel, interest and depreciation). This brings the total cost to $495.50 per day, or $165 per mile, including the erecting of the telegraph line, but not including the cost of surfacing the track. On one occasion the above force laid 4 miles in 10 hrs. In dry open country, like North Dakota, this method was faster than working with track machines and no more expensive. In swamp, very hilly or timbered country, the tracklaying machines are especially serviceable.

The track surfacing gangs followed the tracklayers and surfaced the track so as to make a safe roadway and prevent bending of the rails and splices before the ballasting was done. These gangs numbered 40 to 45 men under a foreman and sub-foreman. About 250 men were required for surfacing, and they went to and from work on hand cars, their boarding cars being located on the sidings

which were put in about every 10 miles. If these men received $1.50 per day, the surfacing cost $375 per day, or $125 per mile. Hence the total cost of laying and surfacing would be $290 per mile.

Cost of Tracklaying, 50-lb. Rails.—In 1881 the following gang averaged one mile of track laid per day by contract. The track was not surfaced by this force.

This does not include the cost of "surfacing," nor does it include "train service."

	Per day.
Tie gang.	
1 panel spacer, at $1.50	$ 1.50
1 tie surfacer, at $1.50	1.50
2 tie liners, at $1.50	3.00
3 tie unloaders, at $1.50	4.50
6 tie spreaders, at $1.50	9.00
1 waterboy, at $1.25	1.25
1 foreman, at $3.00	3.00
Iron gang.	
1 gager, at $2.00	2.00
2 heelers, at $2.00	4.00
2 unloaders, at $2.00	4.00
6 iron men, at $2.00	12.00
1 waterboy, at $1.25	1.25
1 foreman, at $3.00	3.00
Front gang.	
1 tie spacer, at $1.50	1.50
1 spike peddler, at $1.50	1.50
2 nippers, at $1.50	3.00
4 spikers, at $2.00	8.00
5 strappers, at $1.50	7.50
1 waterboy, at $1.25	1.25
1 foreman, at $3.00	3.00
Tie loading gang.	
16 men (4 gangs of 4 each), at $1.50	24.00
1 waterboy, at $1.25	1.25
1 foreman, at $3.00	3.00
Backspiking gang.	
1 tie spacer, at $1.50	1.50
2 spike peddlers, at $1.50	3.00
4 nippers, at $1.50	6.00
8 spikers, at $2.00	16.00
1 waterboy, at $1.25	1.25
1 foreman, at $3.00	3.00
Lining gang.	
5 men, at $1.50	7.50
1 waterboy, at $1.25	1.25
Backfilling gang.	
15 men, at $1.50	22.50
1 waterboy, at $1.25	1.25
1 foreman, at $3.00	3.00
Hauling gang.	
18 teamsters, at $1.80	32.40
1 waterboy, at $1.25	1.25
40 mules' feed, at $0.40	16.00
1 wagon master, at $3.00	3.00
General force.	
1 camp boss, teamsters' camp, at $2.25	2.25
1 blacksmith, at $2.25	2.25
2 night watchmen, at $2.25	4.50
1 tool man, at $2.00	2.00
1 bookkeeper, at $4.00	4.00
1 superintendent, at $5.00	5.00
Material train, fuel and wages	24.00
Total per day and per mile	$266.90

The force, as above given, can lay 1½ miles of steel track per day, but cannot keep up the back work and average much more than one mile. All ties are full spiked; 15 ties to a 30-ft. rail; 50-lb. steel rails. The ties and steel are delivered to the contractor on cars at the last side track; and side tracks are about 8 miles apart.

A material train is made up of 10 tie cars, each holding 135 ties, and 3 steel cars, each holding 60 rails. This train is at the boarding train at 6 a. m., in time to take the force to the front after breakfast. The backfillers, liners and backspikers are dropped where work had stopped the day before, and the 10 cars of ties (which are in the rear of the locomotive) are uncoupled far enough back to give the train room to move ahead with the 3 cars of steel (which are in front of the locomotive) as far as the "iron car" upon which 30 rails at a time are loaded and pushed up front. The two unloaders in the iron gang assist in loading the iron car; and, while the rails on the iron car are being laid, they throw off another 30 rails from the flat cars ready to be loaded on the iron car. The 10 cars of ties are brought up as fast as the track will allow, and only enough are unloaded by the tie loaders at one time to keep the wagons busy. At noon the train carries the force back to dinner, the empty flat cars are sidetracked, and another train of 10 tie cars and 3 steel cars brought up in time to take the men back after dinner.

In laying the track, the panel spacer with a 30-ft. pole and pick keeps far enough ahead to do duty as the roadmaster. The front gangs of spikers (2 on each rail) spike 3 ties in each panel, always the joint and the 6th and 11th ties, skipping 4 ties each time. Of the 5 strappers, one untrims the plates, leaving plates, nuts and bolts on the joint tie, and the other 4, working 2 on a side, strap up and bolt the joints. Should the backspikers get behind, they are assisted by the frontspikers. Should the backfillers get behind, they are reinforced by the tie gangs, and the iron gang and strappers can be putting in the sidings.

Of the teams, 16 are used to haul ties, 1 to pull the iron car, and 1 to haul water to the boarding train. The 16 teams haul 14 loads of 12 ties each per day, making 2,688 ties.

Cost of Tracklaying on the A., T. & S. Fe R. R.—With a well-organized force the cost of laying and surfacing the Arkansas City extension of the A., T. & S. Fe, in 1888, was $292 per mile for a month's work. On the same road the following force laid 2 miles per day:

Laying.	Per day.
15 men running iron cars, at $1.75	$ 26.25
2 men unloading iron, at $1.75	3.50
24 men spiking, at $1.75	42.00
8 men strapping, at $1.75	14.00
5 men spacing ties and "squaring" joints, at $1.75	8.75
4 men lining track, at $1.75	7.00
7 men setting "joint and center" ties, at $1.75	12.25
2 men carrying gages, at $1.75	3.50
2 men distributing spikes, at $1.75	3.50
1 man caring for tools, at $1.75	1.75
42 men bedding ties, at $1.40	58.80
12 men ("nippers"), at $1.40	16.80
18 men handling ties, at $1.40	25.20
2 men stretching tie line, at $1.40	2.80
4 men carrying water, at $1.40	5.60
1 general foreman	3.33
1 foreman iron car	2.50
1 foreman tie bedding	2.50
1 foreman handling ties	2.50
1 foreman tracklining	2.50
1 foreman spiking gang	2.00
10 extra men, at $1.40	14.00
22 teams hauling ties, at $3.50	77.00
1 team hauling iron car, at $3.50	3.50
Total laying 2 miles at $170.76	$341.53

In addition to this the surfacing of 2 miles of track per day cost as follows:

Surfacing.	
80 shovelers, at $1.40	$112.20
2 "back-bolters," at $1.75	3.50
1 foreman raising track	2.00
1 foreman	2.50
Total surfacing 2 miles at $60.10	$120.20

Train Service and General.	
Superintendent of tracklaying	$ 5.00
Timekeeper	3.00
Train and engine crews	15.04
Engineering	10.97
Total, train crews, etc., 2 miles at $17.00	$34.01

Summary.	Per mile.
Tracklaying	$170.76
Tracksurfacing	60.10
Train service, etc.	17.00
Total	$247.86

This does not include the cost of supplying and distributing of ballast by train. On the Larned branch 15 miles were laid in 7 days, but under the favorable circumstance of light grades, light work, light earth for ballast, and roadbed in first-class condition.

It will be noted that the cost of "train service" appears not to include the delivery of materials from material yards, nor does it include fuel, and interest and depreciation on plant.

Cost of Tracklaying, A., T. & S. Fe R. R.—Some rapid work was done (1899) in the extension of the A., T. & S. F. Ry. from Stockton, Cal., to Port Richmond. The rails were laid with broken

joints, 17 ties per rail. One stretch of 11 miles (62½-lb. rails) was laid at the rate of 2,846 ft. per day, with a force of 45 men, on level grade. Another stretch of 17 miles (75-lb. rails) was laid at the rate of 3,500 ft. per day, with 48 men, on a descending grade of 1%, with curves at intervals of ½ mile. The best day's work, on the level grade, was 5,400 ft., with 52 men. The force was as follows:

Foreman	1
Sub-foreman	3
Strappers	4
Iron car men	10
Spikers	8
Nippers	4
Tie line man	1
Lining ties	2
Tie plater	1
Spike peddler	1
Spacing ties	2
Spacing rails	2
Back bolting	2
Tie carriers	10
Picking up materials	1
Total	52

Cost of Tracklaying, P., S. & N. R. R.—Mr. G. C. Woollard gives the following on tracklaying on the Pittsburg, Shawmut & Northern R. R. The length of track laid was 8 miles. With a gang of 46 men and 3 foremen the average day's work was 2,870 ft. of track laid; the best day's work was 3,290 ft. There were 18 men and a foreman in the tracklaying gang; 17 men and a foreman in the supply gang; 11 men and a foreman in the backtieing gang. Beside these men there were a locomotive engineer, fireman, conductor and a brakeman. No teams were used. Trucks passed one another by raising one truck to a vertical position on the cross-ties and then allowing it to drop back to an oblique position, keeping it from turning over by means of a prop while the loading truck passed. There were 18 oak ties to a rail, and rails were 85-lb. All the work was on a 2% down grade, which facilitated delivery of materials by gravity.

Cost of Tracklaying with Machines. — Tracklaying machines do not lay the track, but merely facilitate the delivery of ties and rails on a series of rollers from the cars to the tracklaying gang of men. In rugged or swampy country a tracklaying machine is especially economic, because the ties cannot be easily delivered by teams.

With a Holman tracklaying machine, 120 miles of the Washington County Ry. (Maine) were laid in 1899. The best day's work was 2 miles laid in 9 hrs. with 110 men.

On the Burlington & Missouri River Ry., with a gang of 85 men and a Holman machine, 1½ miles per day were laid at a cost of $100 per mile. The rails were 65-lb. rails, with 18 ties to a rail. Curves of 1° to 16° were laid. Equally good work was done with the Harris tracklaying machine.

On the Chicago, Rock Island & Pacific Ry., 1,300 miles of track were laid with a Harris machine in 1886 and 1887. The average cost of laying 2 miles per day was as follows:

	Per day.
1 general foreman	$ 5.00
2 assistant foremen, at $3	6.00
109 laborers, at $2	218.00
1 engine and train crew	20.00
Total, 2 miles, $124.50	$249.00

To this must be added $10 per mile for preparatory work in transferring material to cars in the yard, and $5 per mile royalty for use of the Harris machine, bringing the total to $140 per mile. It will be noted that this does not include the cost of surfacing.

The Harris machine is said to be quicker than the Holman, where long stretches are to be laid; but the Holman is more economical for short stretches or where delays are frequent, as the gang is smaller.

Another machine that has been extensively used is the Roberts.

The Hurley Tracklaying Machine Co., of Chicago, make an excellent machine with which 2 to 4 miles per day can be laid and quarterspiked with a gang of 40 men.

Cost of Laying a Narrow Gage Track.—Where ties and rails are dumped along in small piles, and where no grading has to be done, a gang of 3 men will average 210 ft. of track laid in 10 hrs. This applies to a light 3-ft. gage track made of 30-lb. rails on 6 x 6-in. ties, 5 ft. long, spaced 3-ft. centers. With wages at 15 cts. per hr., the labor cost is practically 2 cts. per ft. of track, or $100 per mile, after the materials are delivered.

A Method of Unloading Rails.—An effective method of unloading rails, along a track where new rails are to be put in, is as follows: The car is provided with a tail board that hangs down and drags along on the track, forming an inclined plane. A hook on a rope is hooked into a rail, and another hook, on the other end of the rope, is hooked over a tie. As the car moves slowly forward the rail is dragged out. By having two of these ropes and hooks, pulling out two rails at a time, 71 rails were unloaded in 25 mins. from a drop end gondola, and 86 rails in 42 mins. from a solid end gondola.

Cost of Renewing Rails on the C., C., C. & St. L. Ry.*—The following is given by Mr. John Barth, and relates to the cost of taking up 80-lb. rail and laying 90-lb. rail.

To unload the new rail I used a rail unloader, which was operated by air, furnished by the work engine, which took a foreman and five men besides the train crew to operate. Any good handy man could run the loader. I made comparison with loading and unloading rail, and found that we could handle the rail considerably

*_Engineering-Contracting_, Oct. 6, 1909.

cheaper with the machine. It cost to unload the new rail and fastenings, per mile:

Labor	$ 9.75
Work train service	9.58
Fuel, oil and waste	7.58
Making, per mile for unloading, a total of	$26.91

This was on single track where we had an average of 17 trains during the 10 working hours. To get the above estimate of cost of unloading I took total cost of unloading 65 miles of rail, and divided by 65 which gives the average cost per mile. Some days we were hung up on account of trains and did very little work, and other days we could do more.

We loaded the old rail with the rail loader, and it cost practically the same to load it as it did to unload the new rail.

In laying this rail I used gangs of one foreman, assistant foreman, timekeeper, and two flagmen, and 44 men. Had my gangs organized as follows:

Six men with claw-bars pulling spikes.

Three men with spike mauls to loosen up spikes that were stuck and to knock down stubs.

Four men throwing out the old rail.

One man with nipping bar to cant the old rails up out of the old bed, and 3 men to shove it out.

Three men driving plugs in the old holes, which should be distributed ahead of the work.

In taking up light rail and laying heavier rail, pull the outside spikes. In doing this, I had 1 man with an adze to adze off the very highest ties only and to cut off the plugs that stick up.

Twelve men with tongs to set in the new rail, which should be set in one rail at a time.

One good hustling fellow to put in the expansion shims and keep the rail gang moving, using steel cut nails for shims, making the expansion according to the thermometer by using different sizes of nails, putting the nail in crosswise against the ball, so that it will be out of the way in putting on the angle bars. The first few trains over, this nail will slip out.

Two men with bars with claws on one end and pointed on the other to shove the rail into the spikes at center and quarters.

Four men with spike mauls. These men start off leaving eight ties unspiked between each man, and go ahead, each man spiking every eighth tie from the last one that he spiked. This spikes every other tie, and prevents the men running around each other.

One man with a claw bar and adze to pull out the spikes that come in the way of the angle bars at the new joint, and to adze down the high ties at the new joint.

Five men putting on angle bars, and bolting up, putting two bolts at each joint, all bolts and angle bars to be distributed ahead of the rail laying for each day's work only. Have plenty of wrenches and spike mauls, and when connection is being made, or waiting for

trains, turn the men that are working in the tong gang and those throwing out rail, back to do full bolting and full spiking.

Two men with a push car, to keep the connection rails, off-set splices, and everything needed in making a connection, and extra tools, right up with the rail-laying, so that when connection is to be made they will be on the ground. Have the spikers and bolters in starting out assist these two men in loading the connection rails. Always move the last new rail ahead and use it as a connection rail all the way through. This will always give you a good joint.

The foreman should watch the time of the regular trains, and go ahead of the spike pullers, and pick out his place for making a connection, and have four picked men out of the gang that set in the rail to make the connection, using short pieces of rail. I used pieces from 4 ft. to 4 ins. long and used off-set bars from 90 lbs. to 80 lbs. I always found that my new rail fell short. I was putting down 33-ft. rail and taking up 30-ft. rail, and every ten rail lengths we could make a good connection by pulling the 80-lb. rail against the 90-lb. and using short pieces of 80-lb. rail to fill in the gap. In closing up at night, if I thought it necessary, I would cut in a long piece of rail.

The two men handling the push car and keeping the tools and connections up with the rail laying, should also keep the tools in good repair, such as keeping handles in the mauls, and have a general supervision of the tools.

The assistant foreman should be back among the workmen and see that the track is kept safe spiked and bolted, and ready for trains by the time a connection is made.

Section men should follow up and tamp any ties that may be hanging or shim them up as the season of the year may require.

Gage the track when you space the ties, as you will have to do it at that time any way, and it avoids cutting up the ties with spikes.

In taking up 80-lb. rail and putting down 90-lb. rail, pull the outside spikes of both rails. In doing this you avoid adzing, as the new rail will set up on the shoulder of the tie on the outside and give the wheels a full bearing on the ball of the rail. In taking up and laying rail of the same size, pull the inside spikes on both rails, and adze the ties down so as to give the wheel a perfect bearing on the ball of the rail. To do this it would take five extra men to do the adzing above the 44.

Full bolt and spike the new rail and uncouple the old rail as far as you go each day. This usually can be done while waiting on trains. If not, take the time to do it. This is the reason I did not work larger gangs of men, as 44 or 46 men just about cleaned up each day's work even.

This rail laying was done on single track where we had an average of 17 trains in our 10 working hours, and was laid at a cost of $134.24 per mile. We laid an average of 3,500 ft. of rail per day.

Since there are 141 tons of 90-lb. rails per mile, this cost is equivalent to $0.95 per ton.

Rail Relaying Gang.*—At the last annual convention of the Roadmasters' and Maintenance of Way Association a committee report was read on relaying rail and the organization for the work. According to the report 51 men will make a good rail gang for 85 to 100-lb. rails, this gang being made up as follows: 1 foreman, 1 assistant foreman, 12 men on the tongs, 7 men pulling spikes, 6 men adzing, 1 man plugging spike holes, 4 men throwing out old line of rails, 10 men spiking, 5 men bolting, 2 flagmen, 1 tool man, and 1 water man. All rails should be laid one at a time, except in a yard where business is too heavy to permit of the use of the tracks. Heavy adzing should, if possible, be done in advance of rail laying.

A gang of this size can lay one mile of track per day on the average railroad. At this rate, and assuming wages to average $2 per man, it would cost $100 per mile for relaying rails.

Labor Cost of Renewing Rails.—During a traffic of one train per hour, in winter, the cost of taking up old rails, unloading and placing new 72-lb. rails on a single track, was $140 per mile. The wages of common laborers were $1.25 per 10 hrs.

Labor Cost of Renewing Rails.—In 1904 and 1905, old 72-lb rails were taken up and new 85-lb. rails laid on certain sections of track in the state of Washington at the following costs per mile. The first work involved 27 miles of single track.

	Per mile.
Unloading and distributing	$ 34.60
Laying and surfacing	294.15
Picking up and piling old steel	38.15
Total	$366.90

Since 85-lb. rails weigh 134 tons per mile, the labor cost of renewing these rails was $2.75 per ton.

On another 18-mile stretch, the cost was as follows:

	Per mile.
Unloading and distributing	$ 35.05
Laying and surfacing	393.70
Picking up and piling old steel	38.60
Total	$467.35

This is equivalent to nearly $3.50 per ton, which is an unnecessarily high cost. The wages of laborers were $1.75, and of spikers $2.25 per day.

Cost of Laying Side Tracks and Switches.†—Practically nothing has ever been printed as to the cost of laying sidetracks and spurs. We purpose giving in this article eight examples of the actual cost of this sort of work on a western railway.

The grading was done, in most cases, by contract and its cost is not included in the following costs, unless specifically mentioned. The tracklaying and surfacing were done by company forces.

**Engineering-Contracting*, Jan. 15, 1908.

†*Engineering-Contracting*, Nov. 4, 1908.

Example 1.—This is a spur track 400 ft. long.

Labor.	
8 days, foreman at $1.50	$12.00
16 days, laborers, at $1.25	20.00
Total labor, 400 ft. at $0.08	$32.00
Materials.	
158 cedar ties at $0.35	$ 55.30
1 set stub switch ties, 3,200 ft. B. M. at $15	48.00
800 ft. S. H. (second hand), 56 lb. rail, 6 and 1886/2240 tons at $16	109.31
52 S. H. angle bars, 728 lbs., at $1.37	9.97
100 S. H. track bolts, 85 lbs., at $1.95	1.66
400 lbs. new spikes at $1.85	7.40
1 frog (56 lb.)	8.00
1 S. H. switch lock	0.25
2 S. H. 2 way switch chairs, 190 lbs., at $1.65	3.14
6 connecting rods, 5′ 2″, at $1.35	8.10
1 S. H. long connecting rod	2.50
1 high switch stand, 2 way	8.00
Total materials	$261.63
Grand total, 400 ft., at $0.73	$293.63

Example 2.—This work involved putting in a switch to connect two tracks, the length of track laid being 118 ft.

Labor.	
4½ days, foreman at $1.80	$ 8.10
14½ days, laborer at $1.25	18.13
4 days, laborer helping engineer stake out spur, $1.25	5.00
Total labor, 118 ft. at $0.265	$31.23
Materials.	
19 S. H. switch ties at $0.10	$ 1.90
1 set switch ties, 2,677 ft. B. M. at $14	37.48
108 ft. new 75 lb. rail, 1 460/2240 tons, $27	32.54
127 ft. S. H. 75 lb. rail, 1 935/2240 tons, $16	22.68
22 new 25 lb. angle bars, 528 lbs., $1.45	7.66
62 track bolts, 52.7 lbs., $2.00	1.05
256 track spikes, 143.4 lbs., $1.68	2.41
1 new 75 lb. 1-7 frog	16.65
1 new sw. lock	0.46
1 S. H. sw. stand, 2 way, low	4.40
2 new switch points (75 lb.) at $7.40	14.80
12 new tie plates at $0.25	3.00
8 new rail braces at $0.155	1.24
1 main rod	0.90
3 connecting rods at $0.50	1.50
8 clips at $0.27	2.16
24 clip bolts, 12 lbs., at $3.10	0.37
1 S. H. short connecting rod	1.10
Total materials	$152.32
Grand total, 118 ft., at $1.55	$183.55

Example 3.—This work consisted in putting in a passing track 2,500 ft. long.

Labor tracklaying.	
20 days, foreman at $1.80	$ 36.00
78 days, laborer at $1.35	105.30
Total labor, 2,500 ft. at $0.056	$141.30

Materials.

2 S. H. head blocks, 224 ft. B. M., at $6	$ 1.34
1,245 S. H. ties at $0.145	180.53
2 sets sw. ties, 34,045 ft. B. M., at $20.00	68.09
42 planks (3 x 12-16), 2,016 ft. B. M., at $11	22.17
4,969 ft. S. H. 56 lb. rail, 41 911/2240 tons, at $16	662.51
340 S. H. A bars, 4,590 lbs., at $0.88	40.39
182 new trk. bolts, 155 lbs., at $1.85	2.86
592 S. H. trk. bolts, 503 lbs., at $1.40	7.04
5,100 spikes, 2,856 lbs., at $1.65	47.12
2 frgs (1-9), 60 lbs., at $13.25	26.50
2 H. T. 2 way sw. stands at $7.25	14.50
2 long conn. rods at $2.10	4.20
2 S. H. conn. rods at $1.05	2.10
14 S. H. conn. rods at $0.53	7.42
8 sw. stand bolts, 12 lbs., at $2.25	0.27
8 sw. nuts	0.33
40 sw. chairs (60 lb.), 357 lbs., at $1.45	5.18
2 sw. locks at $0.29	0.58
2 S. H. guard rails (60 lbs.) at $1.27	2.54
Total materials	$1,695.67
4,720 cu. yds. grading at 13 cts	613.60
Labor ballasting.	
5½ days, foreman at $1.80	$ 9.90
11 days, laborer at $1.35	14.85
Total labor ballasting	$ 24.75
Grand total, 2,500 ft., at $0.75	1,875.32

Example 4.—The work consisted in laying a passing track 2,500 ft. long, including grading, ballasting and surfacing.

Labor grading:	
15 days, foreman at $1.80	$ 27.00
10 days, laborer at $1.25	22.48
195 days, team at $3.50	682.50
Total grading	$ 731.98
Labor laying track.	
4 days, foreman at $1.80	$ 7.20
80 days, laborer at $1.25	100.00
Total, 2,500 ft. at $0.043	$ 107.20
Labor moving a switch.	
1 day, foreman	$ 1.80
8½ days, laborer at $1.25	10.63
Total	$ 12.43
Labor surfacing track.	
4 days, foreman at $1.80	$ 7.20
20 days, laborer at $1.25	25.00
Total	$ 32.20
Work train service ballasting.	
1.4 days, engine service (140 mi.) at $27.50	$ 38.50
1.5 days, conductor at $80 mo.	4.44
3 days, brakeman at $60 mo.	6.67
Total	$ 49.61

Materials.

4,760 lin. ft. S. H. 56 lb. rail, 39 1493/2240 tons, at $16	$ 634.66
128 lin. ft. S. H. 50 lb. rail, 2133/2240 tons, at $16	15.24
1 new No. 9 frog	13.25
1 new No. 1 frog (56 lb.)	12.25
4 guard rails at $1.27	5.08
1,088 ties at $0.23	250.24
2 sets sw. ties, 5,354 ft. B. M., $12.00	64.25
4 H. B. bolts, 12 lbs., $2.25	0.27
318 S. H. 56 lb. A bars, 4,452 lbs., $0.88	39.18
2 sw. stands, $7.25	14.50
12 S. H. 50 lb. splice bars, 108 lbs., $0.88	0.95
8 sq. nuts, 2 lbs., $2.90	0.06
648 new track bolts, 551 lbs., $1.85	10.19
2 sw. locks, $0.45	0.90
4,990 new track spikes, 2,974 lbs., $1.65	46.11
2 long conn. rods, $2.10	4.20
4 new 2 way sw. chairs, cast 382 lb., at $1.45	5.54
2 new tie rods, $1.10	2.20
10 new conn. sw. rods, $1.10	11.00
8 rail braces, $0.91	0.73
12 crossing plank (3 x 12—16), 576 ft. B. M. at $10.00	5.76
12 lbs. spikes, $1.85	0.22
2 sets frog blocking, $1.20	2.40
Total materials	$1,139.18
Grand total, 2,500 ft. at $0.829	$2,072.60

Example 5.—This is an industry spur 550 ft. long, and the cost of labor only is given. The rail was 56-lb., and the cost of materials can be easily estimated from the examples previously given.

10 days, foreman, $1.80	$ 18.00
30 days, laborer, $1.50	45.00
24 days, team and driver, $4.00	96.00
Total, 550 ft., at $0.28	$159.00

Note the high cost due to team work.

Example 6.—This consisted in making an extension 180 ft. long to an existing spur, so that no switch was put in.

Labor:

3.6 days, foreman, at $55 mo	$ 6.75
11.6 days, labor, at $1.50	14.16
4.8 days, labor, at $1,20	5.04
Total labor, 180 ft., at $0.144	$25.95

Material:

360 ft. S. H. 60-lb. rail, 3 480/2240 tons, $24.20	$ 77.79
.24 S. H. A. bars, 342 lbs., $1.53	5.23
190 track spikes, 106 lbs., $1.59	1.69
48 S. H. tr. bolts, 41 lbs., $2.04	0.84
90 treated ties, $0.36	32.40
Total	$117.95
Grand total, 180 ft., at $0.80	$143.90

Example 7.—This consisted in building an industrial spur 550 ft. long. The low cost of the labor should be noted, as compared with that in Example 5, where an inordinately high team cost appears.

Engineering:	
8 hrs. asst. engr., at $100 mo.	$ 2.58
8 hrs., roadman, at $50 mo.	1.29
8 hrs., chainman, at $40 mo.	1.03
Total engineering	$ 4.90
Labor:	
55 hrs. foreman, at $55 mo.	$ 9.75
475 hrs. laborer, at $1.25 day	59.20
Total labor, 550 ft., at $0.126	$ 68.95
Material:	
1,052 ft. S. H. 56-lb. rail, 19,637 lbs., at $24.20	$212.10
30 ft. scrap rail (56-lb.), 560 lbs., at $7.37	1.84
76 A bars (56-lb.), 1,083 lbs., at $2.25	27.62
129 lbs. tr. bolts, at $3.19	4.12
700 lbs. tr. spikes, at $2.98	18.06
1 rigid frog (1-9), 60-lb.	21.05
1 sw. stand	6.68
4 sw. bolts	0.20
1 long conn. rod	2.33
1 split sw. compl. (60-lb.)	23.52
2 guard rails, 10 ft., 50-lb.	6.56
12 S. H. rail braces, 8½ cts.	1.02
1 sw. lock	0.38
1 set sw. ties, 3,283 ft. B. M., at $8.50	27.91
1 sand bumper	9.20
Total materials	$362.59
Grand total	$436.44

It will be noted that no charge for cross ties (other than the set of sawed switch ties) is made. Hence the cost of materials is incomplete.

Example 8.—This is a crossover track, 496 ft. long.

Engineering:	
1 day, asst. engr.	$ 2.75
1 day, rodman	1.60
1 day, chainman	1.30
Engr. expense	4.35
Total	$ 10.00
Labor:	
Putting in sw. ties and grading new crossover track:	
1.5 day, foreman, at $75 mo.	$ 3.75
1.5 day, timekeeper, at $60	3.00
1.5 day, asst. foreman, at $60	3.00
38 day, laborers, at $1.75	67.35
Total	$ 77.10
Putting in crossover track:	
1 day, foreman, at $75	$ 2.42
1 day, timekeeper, at $60	1.93
1 day, asst. foreman, at $60	1.94
39.8 day, laborers, at $1.75	69.65
Total	$ 75.94

Surfacing crossover track:

0.4	day, foreman, at $75	$ 0.97
0.4	day, asst. foreman, at $60	0.97
0.5	day, timekeeper, at $60	0.96
11.5	day, laborers, at $1.75	20.10
	Total	$ 22.80

Materials:

50	ft. 80-lb. 1st qual. rail, 1,333 lbs., at $29.30	$ 17.43
87	ft. 80-lb. 2d qual. rail, 1 80/2240 tons, at $29.30	28.89
679	ft. S. H. 68-lb. rail, 6 1951/2240 tons, at 24.20	166.27
41	S. H. ties, at $0.10	4.10
130	treated ties, at $0.37	48.10
1	set sw. ties	27.81
1	set sw. ties	22.51
14	new 24-in. 80-lb. A bars, 290 lbs., $1.30	3.77
2	new W. joints, $0.96	1.92
50	S. H. 36-in. 68-lb. A bars, 1,200 lbs., $0.98	11.76
4	new 24-in. offsets, 68 lbs., $1.37	0.93
185	new tr. bolts, 157 lbs., $2.48	3.89
1,331	new spikes, 745 lbs., $1.88	13.97
1	new No. 9 sprg. rail frog (77½-lb.)	35.50
1	new No. 7 frog (68-lb.)	13.70
1	S. H. sw. stand	2.98
1	new sw. stand	5.55
8	sw. stand bolts, 14 lbs., $3.66	0.51
1	sprg. switch comp., 15 pts. (68-lb.)	18.11
1	sprg. switch comp., 15 pts. (68-lb.)	9.41
1	S. H. long conn. rod	0.70
1	short conn. rod	0.34
2	guard rails comp. (80-lb.)	13.65
2	S. H. 68-lb. guard rails, 680 lbs., $13.80	4.19
2	sw. locks repd., $0.18	0.36
2	sets frog blocking, $0.15	0.30
1	sw. lamp	1.85
68	new tie plates, 273 lbs., $2.15	5.87
415	S. H. tie plates, 1,177 lbs., $1,875	22.07
9	S. H. wall rail braces, 22 lbs., 11.05 cts.	0.12
	Total material	$486.56
	Grand total, 496 ft., at $1.366	$672.40

The high cost of the labor is attributed to "extra labor expended in clearing and to considerable interference by switch engine, this work being done in the yards."

Summary.—On short sidetracks or cross-overs the cost of putting in a switch constitutes a much larger percentage of the total cost than on long sidetracks. Hence the cost of labor, as well as of materials, is greater per lineal foot of short sidetrack than of long sidetrack.

Estimated Cost of Growing Tie Timber.*—In a paper read before the Engineers' Club of Philadelphia, Mr. E. A. Sterling, Forester of the Pennsylvania Lines, stated that in their work on the Pennsylvania Lines east of Pittsburg and Erie, over 2,000,000 trees had been planted on lands acquired in connection with widening and straightening the main line, and in the construction of low

**Engineering-Contracting,* April 22, 1908.

grade lines. The actual cost of plant material and planting last spring was $11.29 per thousand trees.

Mr. Sterling gave the following as an estimate of the returns per acre, which may be expected from such work, if red oak is planted on land valued at $10 per acre, with interest at 4½%, compounded annually, and the crop maturing in 40 yrs.:

Land at $10, at 4½%, for 40 yrs.	$ 58.16
Plant material and planting $10, at 4½% for 40 yrs.	58.16
Taxes, 3 cts. per annum, at 4½% for 40 yrs.	3.21
Management and protection, 15 cts., at 4½% for 40 yrs.	16.05
Sawing or hewing 400 ties, at 10 cts.	40.00
Hauling 400 ties, at 5 cts.	20.00
Total, 400 ties, at 48 cts.	$195.58

By the above estimate 400 ties would be produced per acre every 40 yrs. at a cost of 48 cts. each, including compound interest charges at 4½%. Mr. Sterling states that the estimate of 40 yrs. will hold for red oak and Scotch and red pines; while chestnut should make ties in 30 to 35 yrs. and locust in 25 to 30 yrs., if not eaten up by the borers. The trees at the end of this period should average 15 ins. on the stump. The tax rate of 3 cts. per acre, used above, is far below the present rate, but is what would be considered a fair charge in a European forest.

Cost of Making Hewed Ties.—From a pine tree that is 14 ins. diameter at the height of a man's shoulder, from 3 to 5 pole ties may be made. The ties are hewed 8 to 8½ ft. long, 6 ins. thick, with two hewed faces 8 ins. wide, and the bark on the sides is peeled with a tie peeler. It is said that a skillful man can cut and make 40 to 50 of these ties per day; but it would not be safe to figure on such an output. In the state of Washington, 25 to 35 fir ties per man per day are a fair output. This includes cutting down the small fir trees from which the ties are made. The men who do this work are called "tie hackers."

In Missouri 25 white oak ties per man per day are regarded as a good output, the men receiving 10 cts. per tie.

A Cheap Way of Loading Ties.—The following described device is simple and well adapted to handling other materials than ties. It consists of an overhead trolley, traveling on a 4-in. I-beam that serves as a rail. In loading box cars with ties, one end of this I-beam is supported on a light wooden A-frame, 7 ft. high and standing about 15 ft. from the car door; the other end of the I-beam enters the car door, and inside the door it is fastened to two bars (¼ x 3 ins.) that branch, forming a Y with curved branches, so that one trolley can run toward one end of the car, another trolley toward the other end. The trackway in the car is hung from the roof rafters by clamps. From each of the trolleys is suspended, by a chain, an L-shaped tie stirrup for carrying a tie. Two men unload a tie from a truck and place it on the tie-stirrup, one man (one on each trolley) runs the tie into the car, the track having a slight down grade, and one man (one at each end of the car)

assists in unloading and piling. The man then takes the trolley off the track and carries it back to the loaders. Thus with a gang of 6 men as much work is done as with 10 men unaided by this device. A gang of 6 men loaded 3,325 large creosoted hewn ties in 9 hrs., no effort being made to make a record. When timed they unloaded a truck of 30 ties into the car in 2 mins. Creosoted ties weigh 200 to 250 lbs. each, and as one man by using a trolley can easily transport them it is evident that much labor is saved. I would suggest the use of a similar device for handling sacks of cement (2 sacks on a double stirrup), for handling brick, two-man stone, etc.

Cost of Burnettizing Timber and Ties.*—The following data relate to the cost of treating timber by the zinc chloride process, known as burnettizing. The extremely low cost of preserving timber in this manner will doubtless astonish many of our readers who are more familiar with the relatively high cost of creosoting. In this article we shall show that burnettizing costs about $2.50 per 1,000 ft. B. M., or 3 cts. per cu. ft.; and in a subsequent article we shall give similarly detailed figures showing a cost of $16 per M, or 19 cts. per cu. ft. for creosoting.

The plant has a capacity of 2,500 ties per day, and the following is the average cost of a year's work:

	Cts. per cu. ft.
0.3 lb. zinc chloride, at 3.8 cts.	1.14
Fuel, at $3.50 per ton	0.25
Oil, etc.	0.06
Current repairs	0.10
Switching engines, etc.	0.10
Depreciation, 10% of $75,000 plant divided by 2,500,000 cu. ft.	0.30
Labor	1.05
Total per cu. ft.	3.00

The ties were 7 x 9 ins. by 8 ft., containing 3.5 cu. ft. each, hence the cost per tie and per 1,000 ft. B. M. was as follows:

	Cts. per tie.	Per M ft. B. M.
Zinc chloride, at 3.8 cts. lb.	4.00	$0.95
Fuel	0.87	0.21
Oil, etc.	0.21	0.05
Current repairs	0.35	0.08
Switching engines, etc.	0.35	0.08
Depreciation	1.05	0.25
Labor	3.67	0.88
Total	10.50	$2.50

The amount of zinc chloride per cubic foot is somewhat less than is commonly used, being 0.3 lb. as compared with 0.4 to 0.5 lb. per cu. ft.

Cost of Burnettizing Ties on the S. P. Ry.—On the Southern Pacific Ry., in 1893, the cost of burnettizing ties was 9½ to 12 cts.

**Engineering-Contracting,* July 3, 1907.

per tie 6 x 8 ins. x 8 ft. About 221,000 "sap" ties were treated during the year, these ties being purchased at the mills in Texas for 23 cts. each.

Cost of Creosoting Piles and Ties.*—In our issue of July 3 we gave the itemized cost of burnettizing ties, the total cost being $2.50 per 1,000 ft. B. M., or 10½ cts. per tie of 7 x 9 ins. x 8 ft. The following data relate to the cost of creosoting ties and piles. Creosoting is a much more expensive process, but the burnettizing treatment is of no use where timber is constantly exposed to the action of water, as is the case wherever piles are used. Water leaches out the zinc chloride in a comparatively small time whenever the timber is constantly submerged, and, even where it is exposed to frequent rains the zinc chloride is dissolved little by little until there is no longer enough left in the timber to protect it from the fungus of decay. Could someone devise a method of filling the outer pores of burnettized wood with some waterproof compound it would be possible to use the zinc chloride for preserving the body of timber that is exposed to water. For example, it might be practicable to treat the surface of burnettized timber with the Sylvester process which has been so successfully used in waterproofing masonry, namely, by coating with soft soap and alum in such a manner as to fill the pores with a curd like precipitate. Indeed, it might be practicable to treat timber, first with zinc chloride and subsequently with creosote, so that the creosote would form the outer protective shell.

The following costs represent the average of a year's work in a plant having a capacity of 500,000 cu. ft., or 6,000,000 ft. B. M. per annum.

The cost of treating the timber was as follows, per cu. ft.:

	Cts. per cu. ft.
1.05 gals. creosote, at 11.5 cts.	12.08
Fuel ($3.50 per ton) and other supplies	1.82
Labor	3.75
Depreciation, maintenance and repairs	1.50
Total	19.15

This is equivalent to $16 per 1,000 ft. B. M., which is more than six times as expensive as burnettizing.

A 7 x 9-in. x 8-ft. tie contains 3.5 cu. ft., hence the cost of creosoting each tie was 67 cts., as compared with 10½ cts. by the zinc chloride process (burnettizing).

About 300,000 lin. ft. of piles were creosoted, and it was found that the piles average 1.11 cu. ft. of timber per lin. ft. of pile. Hence the cost of creosoting was 21¼ cts. per lin. ft. of pile.

In analyzing the above costs per cu. ft. it will be noted that the item of depreciation and maintenance is 1.5 cts. per cu. ft., which is equivalent to $1.80 per M. This item is based on an allowance of 10% per annum for depreciation of a $75,000 plant, plus current repairs and insurance.

*_Engineering-Contracting_, Aug. 7, 1907.

See the section on Timber in this book for further data on creosoting.

Cost of Treating Ties With Zinc Chloride and Creosote, Galesburg, Ill.*—The Chicago, Burlington & Quincy Ry. has built a plant for treating ties at Galesburg, Ill. The plant is situated on a tract of 80 acres with a space for tracks having a capacity of 2,000,000 ties, although at present there are tracks for a storage of only 1,000,000. For fire protection in the yard, hydrants are spaced 300 ft. apart, being supplied with water from a 100,000-gal. storage tank, fed by a well 1,300 ft. deep. The tracks in the yard are laid with three rails, as narrow gage cars are used to deliver the ties to the retorts.

The plant was located at Galesburg as it is the connecting point of the Burlington lines with the south, the principal source of the supply, and on this part of the system there are always available stock cars for the shipment of the treated ties. Box cars cannot be used for this purpose on account of the odor which is retained in the cars when loaded with creosoted timber.

The main building is 152 x 115 ft., divided into three rooms, one containing three retorts, another the engines and tanks, the third being the boiler room. There is also a test room, fitted up for treating four ties. The building is of reinforced concrete throughout. The window sashes are of metal, glazed with wire glass, while the doors are all covered with sheet metal.

The retort room is the full length of the building and 38 ft. wide, the retorts being 132 ft. long and 6 ft. in diameter, made of ⅞-in. steel, furnished by the Allis-Chalmers Co. Each has a capacity of 650 ties, while the plant treats 6,000 ties in 24 hrs.

There are three 150-hp. boilers, one being for emergencies. There is no chimney, induced draft system being used. The engine room, 30 x 115 ft., contains an Ingersoll-Rand compressor, with a capacity of 525 cu. ft. of free air per min., a Knowles fire pump, three Knowles pressure pumps, one Knowles oil pump and one Battle Creek vacuum pump. There is also a small electric light plant in this room.

The tank room, 39 x 50 ft., contains a 25,000-gal. steel working tank and a 100,000-gal. steel mixing tank for creosote. On the outside, close to the main building, are the storage and measuring tanks, one 500,000-gal. steel tank for creosote storage and two 5,000-gal. steel tanks for measuring creosote, two 50,000-gal. wooden tanks for zinc chloride and one 25,000-gal. iron storage tank for zinc chloride. The two steel outside tanks are arranged for heating with steam coils.

The plant is arranged with its pipe connections between pumps, tanks and retorts, so that the straight zinc chloride process, of the two, known as the Card process, may be used on one retort or on all

*_Engineering-Contracting_, Sept. 2, 1908, an abstract of an article in The Railway Age.

three. In the Card process, which is a modification of the Rutger, the zinc chloride and creosote are continuously agitated under pressure by centrifugal pumps, and ordinary coal tar creosote can be used. Each retort is connected with an electrically driven centrifugal pump, which forces the liquid in at the bottom and exhausts it from the top of the retort. The vacuum in retorts is obtained by a Baragwauth barometric condenser, with an auxiliary air pump 6½ x 12 x 12 ins. having a connection with the air chamber of the condenser. The condensing pipes are placed on the roof of the engine room.

The Rutger process has been used in Germany, but it requires a creosote having special qualities and is expensive. In the Allardyce process the zinc chloride is put in first and then the creosote, while the Ruping process aims to reduce the expense for creosote by first filling the wood cells with compressed air and then coating them with creosote.

Seasoned ties are treated directly, but if green they are first steamed under pressure of 5 to 20 lbs. from 1 to 2 hrs. The sap is blown off every 15 to 30 mins. With the Card process a vacuum of 27 to 28 ins. is held on the retort for an hour, and, with the vacuum still on, the mixture of zinc chloride and creosote is run in by gravity, entirely filling the retort, and requires about 18,000 gals. The liquid is heated to 180° F., and at this temperature the two ingredients do not separate as rapidly as in a cold solution. The centrifugal pumps are then started and the liquid is circulated at the rate of 2,500 gals. per min. and the whole charge is changed every 7 or 8 mins. At the same time the pressure pumps are started and pressure gradually increased to 150 lbs. and held at that for 2 to 4 hrs., or until a sufficient amount of the liquid is absorbed by the timber.

The pressure pumps are connected to the 5,000-gal. measuring tanks which have gauges operated by floats, and in this way the volume of liquid forced into the timber is known. When the gauges show a sufficient amount the pressure is released and the remaining liquid is forced back into the mixing tank. Then a vacuum of 24 to 28 ins. is created and held for an hour, taking out all surplus liquid into the underground tanks, where it is allowed to settle and then returned to the mixing tank. This last treatment is for the purpose of removing the surplus creosote remaining on the surface of the ties, so they can be handled comfortably, and 500 gals. saved from each retort.

The retort door is then opened and the cars withdrawn by wire cable operated by electric motor and switched to the platform, where they are loaded directly for shipment. Each tie is marked with a short thick nail having the year of treatment on its head. The ties are loaded by the Anzler loader at a cost of 25 cts. per tram.

An approximate cost of the new plant is as follows:

Land	$ 28,000
Tracks	50,000
Sewers	5,000
Well	6,000
Platform	3,000
Building	30,000
Three retorts	30,000
Tanks of all kinds	10.000
Pipes and valves and labor	20,000
Pumps	6,000
Boiler and settings	5,000
Electric light plant	3,000
Mundy hoists	2,500
	$198,500

Thirty men are employed in the offices and plant, there being a chief engineer and chemist, 2 engineers and 2 assistant engineers for day and night, 3 sub-foremen and 2 motormen, besides the laborers.

The liquid used is a mixture of 17% creosote and 83% zinc chloride solution, the latter containing 3% chloride and the rest water. The creosote has a specific gravity of 1.045 and contains about 35% naphthaline and 5% tar acid. The cost of creosote is 6¾ to 7 cts. per gal.

The cost of treating a pine tie is estimated as follows:

	Per cu. ft.	Per tie (3 cu. ft.)
0.5 lb. dry zinc chloride, at 4cts.	$0.020	$0.060
0.8 lb. creosote, at 3 cts.	0.024	0.072
Labor, fuel, supplies and supt.	0.013	0.040
Interest and depreciation	0.005	0.15
Total	$0.062	$0.187

This figure is the cost during the winter months. The cost is less in warm weather—probably as low as 16 cts. About 46% of the ties treated at this plant are red oaks, and 35% yellow pine, the rest being gum, elm, beech, birch, etc.

The plant was designed under the supervision of T. E. Calvert, chief engineer, and F. J. Creiger, who now has charge of the plant.

It will be noted that at 6.2 cts. per cu. ft., the cost of treatment is equivalent to $5.17 per 1,000 ft. B. M.

Cost of Treating Ties and Their Life.—In 1885 the A., T. & S. F. Ry. began treating ties by the zinc-tannin, or Wellhouse, process. Up to 1901, its cost of treating some 4,000,000 ties is said to have been 15 to 18 cts. per tie.

New Mexico mountain pine ties having a life of 4 yrs. when untreated have a life of of 10½ to 11 yrs. when treated.

In 1886 the Chicago, Rock Island & Pacific Ry. contracted to have ties treated for 16 cts. per tie.

Some 4,750,000 hemlock and tamarack ties had been treated up to 1901, and the average life of these ties has been 10½ to 11½ yrs., depending on location.

In 1887 the Southern Pacific Ry. began burnettizing ties (zinc chloride process) without subsequent treatment. Up to 1901 it had treated 2,500,000 pine ties, which last 4 yrs. when untreated. The life of the treated ties was 7 yrs. where the rainfall was heavy (Glidden Division) to more than 9 yrs. where the rainfall was light (Del Rio Division). The average of all was 8¼ yrs. life.

Not including interest or depreciation of plant, the cost of treatment was only 6.44 cts. per tie, in 1898.

About 0.24 lb. dry zinc chloride was used per cu. ft. of timber, or half the standard used in Europe.

Life of Treated Ties.—The records of treated pine ties taken out of the A., T. & St. F., showed the following averages:

	Life, yrs.
1897	10.18
1898	10.56
1899	10.61
1900	10.78
1901	10.58
1902	10.70

These ties were treated with the two-injection Wellhouse process. These figures relate only to the ties removed on account of rot.

Life of Ties.—For the fiscal year ending June 30, 1901, seven railways reported that untreated oak ties (white, post, burr, etc.) were in use on the following mileage:

	Miles of main line.	Miles of all track.
Chicago and Northwestern (Madison Div.)	614	764
Illinois Central (Eighth Div.)	286	332
Illinois Central (Springfield Div.)	454	552
Nashville, Chattanooga & St. Louis	1,195	1,414
Penn. Lines (Pittsburg Div.)	442	594
Southern Ry. (Eastern Dist.)	3,200	3,749
Southern Pacific (Atlantic System)	2,107	2,607
Total	8,298	10,012

There were 17,471,116 oak ties in these tracks, and 2,147,684, or 12.3% more renewed during the year, which is equivalent to a life of about 8 yrs.

The average life of ties, as estimated by different railways, was as follows:

Railway.	Kind of tie	Life in Years. Main track.	Side track.
Chicago and Great Western	Oak	8	10
Chicago and Northwestern	"	7	10
Illinois Central	"	7	9
Nash., Chatta. & St. L.	"	7	9
Norfolk & Western	White Oak	8.5	9.5
Pitts. & Lake Erie	"	8	10
Boston & Maine	Chestnut	8	12
Illinois Central (Louisiana)	Cypress	9	13

The French State Railway gave the following as the life of creosoted ties:

	Life Years on—		
	Main line.	Siding.	Total.
Creosoted pine	15	5	20
Creosoted oak	18	7	25
Creosoted beech	20	10	30

Estimated Life of Ties in 1894.—Bulletin No. 9 (1894) of the Forestry Division, U. S. Dept. of Agriculture, states that when there were 235,000 miles of track (all main, branch and side tracks) in the U. S., 76,000,000 ties were annually required for renewals. This is equivalent to 324 ties renewed per mile of all tracks. If there were 2,800 ties per mile, the life was 8.7 yrs. The estimate of 76,000,000 ties for renewals may be accurate, since the reports of the railways to the Interstate Commerce Commission give the number of ties used each year for renewals.

Due to the use of heavier rails than were common in 1894 (15 yrs. ago), the life of ties is greater now than then.

Life of Ties as Affected by Weight of Rail.—Mr. P. H. Dudley states that on the New York Central Ry., when 65-lb. rails were used, the life of a yellow pine tie was 8 or 9 yrs. Since the introduction of 100-lb. rails, the life has increased to 11½ yrs. The ties are no longer cut by the rails nor injured by the frequent tamping required with lighter rails. He states (in 1901) that not 5% of the ties are now removed for other causes than decay, whereas 40% of the ties under 65-lb. rails were taken out because of cutting under the rail and other injury. Eighteen ties used per 30-ft. rail length, or 3,168 per mile. The average tie renewals from 1890 to 1900, was 293 ties per mile, or 9¼%, for untreated ties of all kinds.

Spacing of Ties on Different Railways.—In 1901 the following was the spacing of ties on different railways:

	—Ties per mile.—	
	Main track.	Side track.
Baltimore & Ohio	2,850	2,650
Chicago & Great Western	3,000	2,800
Chicago & Northwestern	2,990	2,500
C., M. & St. P.	3,000	2,640
C., C. & St. L.	3,000	2,800
Illinois Central	3,168	2,640
Louisville & Nashville	2,816	2,112
Michigan Central	3,168	2,375
Nashville, Chatta. & St. L.	2,900	2,640
New York Central	3,000	2,500
Norfolk & Western	2,816	2,600
Penn. Lines (Pittsburg Div.)	2,816	2,288
Pittsburg & Lake Erie	2,640	2,640
Southern Pacific (Atlantic Syst.)	2,816	2,664
Southern Ry. (Eastern Dist.)	2,816	2,640
Wabash (Detroit Div.)	2,990	2,800
Union Pacific (2,816 on branches)	2,992	2,640

It is probably very close to an average to say that there are 2,900 ties per mile of main line and branches, and 2,640 per mile of sidetrack and yards, in the railways of the United States. Since there are 0.4 mile of sidetracks and yards per mile of main track

and branches the average of all tracks would then be 2,820 ties per mile of track.

Labor Cost of Renewing Ties.—The cost of distributing new ties, taking out old ties and laying new ones, and disposing of the old ties by burning, averaged as follows for the years 1904 and 1905 on one of the divisions of the Northern Pacific Ry. in Washington:

	Per new tie.
Distributing	$0.028
Laying	0.110
Disposing of old tie	0.009
Total	$0.147

Wages averaged $1.45 per day for section men and $2.00 per day for section foremen. The ties were laid on a gravel ballast.

Prices of Ties and Labor Cost of Renewals.—In 1901 the following was the cost of ties and of placing them in track on several typical railways:

Road.	Kind	Cost deliv. at track	Cost loading on cars	Cost per 100 miles haul.	Cost of distributing	Cost putting in track	Total cost, cts.
So. Pacific	Redwood	38	1	1	½	10½	52½
Mich. Cent.	Oak	45	1½	4¾	1	10	60
Wabash	Oak	40	1½	5	1	10	55
N. Y. Cent.	Y. Pine	59	1½	4	1	10	77½
Louisville & N.	Y. Pine	45	1½	...	...	15	81½
Denver & R. I.	Red Spruce	33	1	½	1	1½	37
Mo. Pacific	Oak	32	1½	5	½	6½	40½
Lake Shore & M. S.	Oak	58	...	...	1½	15	74½
Union Pacific	Oak	56	...	1¾	1½	10	71½
Union Pacific	Wyo. Pine	40	...	2¼	2	11	57½

Average Price of Ties in America.—The annual reports made by the different railways of America to the Interstate Commerce Commission contain statements of the number of ties used in renewals and of the average price paid for ties at the point of distribution. Unfortunately the reports made by the Interstate Commerce Commission contain none of these data. However, the reports give the total cost of tie renewals each year, which is approximately $130 per mile of all track. If there are 2,800 ties per mile, and if 10% are renewed annually, then the average cost of ties is 46.4 cts. This does not include the cost of distributing and laying the ties. If 11% of the ties are renewed annually, the average cost of ties is 42.2 cts. per tie. It is reasonably certain that, including side tracks and yard tracks, tie renewals (untreated ties) average 10 to 11% per year for American railways, variations from this average depending on kind of wood, climate, weight of rail, etc.

Cost of Gravel Ballast.—A common amount of gravel ballast is 1,600 cu. yds. per mile of track, and rarely need the cost exceed 40 cts. per cu. yd., including the labor of putting the ballast under the ties and surfacing the track. A not unusual contract price is 27 cts.

per cu. yd. for loading ballast on flat cars with steam shovels, unloading with ballast plows, and putting under the ties, and surfacing of track. In addition to this the railway company must pay the cost of hauling the ballast—work train service—which should not exceed 17 cts. per cu. yd. even for a haul of 100 miles.

The following is a typical gang for loading, hauling and unloading ballast:

		Per day.
Steam Shovel.		
1 foreman, $150 per mo.		$ 6.00
1 engineman, $125 per mo.		4.80
1 cranesman, $90 per mo.		3.50
1 fireman, $60 per mo.		2.30
1 watchman, $60 per mo.		2.30
1 timekeeper, $60 per mo.		2.30
6 pit laborers, at $2.00		12.00
6 laborers "throwing" pit tracks and repairing		12.00
Total		$ 45.20
Repairs to steam shovel		8.00
Total steam shovel loading		$ 53.20
Hauling Ballast.		
1 conductor		$ 3.50
2 brakemen, at $2.50		5.00
Engine service on work train.		
1 engineman	$ 4.50	
1 fireman	2.50	
Coal and oil	8.50	
Engine rental and repairs	12.00	
		27.50
Engine service "spotting" cars		27.50
Rental and repairs, 40 flat cars, at $0.50		20.00
Total hauling ballast		$ 83.50
Unloading and Distributing Ballast.		
1 operator of unloading plow		$ 3.00
10 laborers, at $2.00		20.00
Coal and oil for unloader		4.00
Rental and repairs of unloader		4.00
Total unloading ballast		$ 31.00
Grand total		$167.70

When this crew is handling 800 cu. yds. of gravel per day the cost is:

	Per cu. yd. Cts.
Loading	6.7
Hauling	10.4
Unloading	3.9
	21.0

In addition to this, the labor cost of tamping ballast under ties and track surfacing is about 12 cts. per cu. yd.

It often happens that gravel pits must be stripped of overlying earth, that considerable grading is necessary for tracks into the pit, that the gravel is cemented and requires some blasting, and that "pit rent" must be paid for the gravel. All these items, however, will rarely amount to 7 cts. per cu. yd., so that the total

cost of the gravel in the track should rarely exceed 40 cts. per cu. yd.

Where traffic on a road is so congested that a ballast train cannot average more than 100 miles traveled per day, and where the load hauled is only 160 cu. yds. per train, it is evident that 5 trips of 10 miles and return will be required to haul 800 cu. yds., and to the figures above given must be added another train for each additional 10 miles of distance from the gravel pit to the dump. However, on long hauls it is obvious that much heavier train loads will ordinarily be used, thus keeping the cost down.

Cost of Gravel and Rock Ballasting Old Track.*—The following matter has been taken from the report of a committee read before the 1907 convention of the Roadmasters and Maintenance of Way Association: On a northern division of the Chicago & Northwestern Ry. the cost of ballasting one mile of track with gravel was $1,020, figured on the basis that 3,400 cu. yds. of material would be used per mile. The gravel was unscreened and unwashed and was used just as it came from the pit. The gravel was placed for a 12-in. raise with standard gravel roadbed on the top of 11½-ft., slope 1½ to 1, and 16 ft. wide from bottom ballast line to ballast line. The itemized cost per cubic yard was as follows:

	Per cu. yd.
Cost of gravel loaded on cars at pit	$0.070
Hauling and unloading, 50-mile haul	0.107
Ballasting	0.123
Total	$0.300

On a division of the Lake Shore & Michigan Southern Ry. for the year 1906 the cost of ballasting with gravel was as follows:

	Per cu. yd.
Gravel, washing and loading	$0.18
Hauling	0.07
Digging out old ballast	0.15
Unloading and placing in track	0.15
Total	$0.55

For crushing limestone ¾ to 1½ ins. in size the cost was as follows:

	Per cu. yd.
Cost of stone	$0.535
Digging out old ballast	0.150
Hauling, unloading and placing in track	0.400
Total	$1.085

For ballasting with crushed stone on a division of the Atchison, Topeka & Santa Fe Ry. the cost was as follows:

	Per cu. yd.
Crushed stone at crusher, loaded on cars	$0.615
Haul, 50 miles	0.055
Labor (Mexican) inserting	0.330
Total	$1.00

Engineering-Contracting, Dec. 25, 1907.

For a 12-in. raise 3,400 cu. yds. of ballast are used per mile, making the cost $3,400. The present standard on this road requires the ballast to be dressed level with the top of the ties for the full length of the tie and 6 ins. beyond the ends of ties, making the top widths of the ballast 9 ft. and giving a slope of 1¾ to 1; this gives a roadbed 16 ft. wide from ballast line on one side to ballast line on the other side, with a 12-in. raise.

Cost of Gravel Ballasting.—About 30 miles of single track railroad were ballasted with gravel sufficient to raise the ties 8 ins. Ties had 10-in. face, were 8½ ft. long, and there were 16 ties to a 30-ft. rail. A 2½-yd. steam shovel was used to load flat cars. About 4 ft. of earth had to be stripped off the gravel pit. The gravel was hauled by two trains of 35 apron flat cars each, each car holding 6 to 7 cu. yds. Two locomotives were used to haul these trains and one locomotive in the pit to spot cars. The cars were unloaded with a plow, and it will be noticed that the damage to the cars caused by the plow was very high. The cost to the railway company per cubic yard of ballast in place was as follows:

	Cts. per cu. yd.
Pit rent	1½
Loading, hauling and dumping	15½
Repairs to cars	5
Shoveling and tamping ballast in track	8
Total per cu. yd.	30

Common laborers were paid $1.25 per 10 hrs.

Cost of Cemented Gravel Ballast.*—There are two principal points in the territory east of Memphis where cementing gravel is worked for the purpose of supplying ballast to railroads; one at Iuka, Miss., on the Southern Ry., known as the Tishomingo Gravel Pit, owned and operated by the Tishomingo Gravel Co., of Memphis, Tenn., and one at Perryville, Tenn., on the Memphis & Paducah Division of the Nashville, Chattanooga & St. Louis Ry., owned and operated by the Perryville Gravel & Ballast Co., of Memphis, Tenn.

As the character of the gravel and the manner of working the two pits are somewhat different, they will be handled separately.

Tishomingo Gravel.—This is a water-worn gravel lying in a compact mass requiring blasting before it can be handled with a steam shovel. It is composed of 20% clay, 5% sand, and 75% gravel. This gravel as a rule is small and none of it large enough to require crushing to make it suitable for ballasting purposes. In order to get it in shape to load with steam shovel, it is loosened up by blasting. This is accomplished by digging a tunnel about 20 x 26 ins. in cross-section into the material a distance of about 26 ft., then turning at right angles for a distance of 10 ft. (see Fig. 8). This digging is done by a man lying down using a pick with a very short handle. The cost of digging these tunnels is 50 cts. per ft.

**Engineering-Contracting*, April 14, 1909.

The charge is placed in the extreme end of the tunnel and a portion of it refilled as shown on sketch. From 75 to 100 carloads of material is loosened up at each blast. This material is then loaded by steam shovel onto cars. The cost of this material is as follows:

	Per cu. yd.
Loading	$0.09
Hauling	0.20
Unloading and distributing	0.07
Putting under ties and surfacing	0.11
Total	$0.47

The advantages of its use are: Small cost, quick cementing qualities, holds track in line and surface well under fairly heavy traffic, does not churn, very little dust and has great resistance to erosion

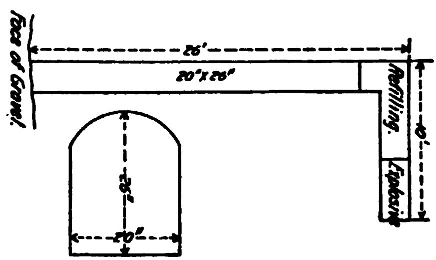


Fig. 8.—Chamber Blast.

by water. Considered an excellent ballasting material. Has the disadvantage of growing prolific crops of weeds and grass, making it costly to keep clean.

Perryville Gravel.—This is an angular gravel lying in compact mass requiring blasting before it can be handled.

Large pockets of clay are encountered, making it preferable to load by hand in order to get the best material. It is composed of 10% clay and 90% gravel, with chemical analysis of 97% silica, 2.5% alumina and 0.5% iron. There is found in this pit considerable large stone, which has to be crushed before it is suitable for use. The cost of this gravel per yard is as follows:

	Per cu. yd.
F. o. b. cars at pit	$0.27½
Hauling, 100-mile train service	0.20
Unloading and distributing	0.04
Stripping, putting under and surfacing	0.20
Total	$0.71½

Cost of Washing Gravel.—A large gravel washing plant was built in 1906 by the Lake Shore & Michigan Southern Ry., at Pleasant Lake on the Ft. Wayne branch of the Lake Shore. The plant handles 3,000 cu. yds. of raw gravel daily. A 75-ton steam shovel with a 3½-yd. bucket loads dump cars, which are dumped into two hoppers that discharge upon two inclined conveyors (made by the Link-Belt Co.), having a capacity of 4,000 cu. yds. per 10-hr. day. The conveyors discharge upon a short flume (8 ft. long) where the gravel encounters the water. Thence the material passes over several fixed screens, all material larger than 2-in. being shunted to a gyratory rock crusher.

The washed gravel for ballast collects in hoppers whence it is drawn off into cars, and the sand (all material larger than ⅛-in.) collects in other hoppers, whence it is drawn off into cars.

The output for a typical day is as follows:

	Cu. yds.
Raw gravel	3,270
Washed gravel	1,335
Washed sand	1,850

The following is the crew required to operate the plant:

1 foreman.
1 clerk.
1 engineman at plant.
1 fireman at plant.
1 shopman.
1 carpenter.
2 men on two sand settlers.
4 men dumping gravel cars.
4 men keeping track clean at washer.
10 men repairing cars and calking ballast cars with hay.
2 locomotive crews delivering gravel.
2 locomotive crews removing washed gravel.
1 steam shovel crew.
30 men in section gang.

The washing plant is driven by a 200-hp. Erie steam engine, but the driving load on the engine is only 132 hp., of which 105 hp. is required to operate the pump supplying the wash water. A 10-in. single-stage centrifugal turbine pump (Worthington), having a 2,400-gal. rating under a 90-ft. head, is used; but the pump is not called upon to deliver more than 1,650 gals.

The cost of the plant and land was as follows:

Plant for washing	$25,000
Land	15,000
Grading	10,000
Bridge work	2,500
Miscellaneous	5,000
Track	36,000
Total	$93,500

Assuming that the gravel pit will be exhausted in 5 years, we have the following annual and daily cost (200 days per year):

	Per year.	Per day.
Plant, 15% of $25,000	$ 3,750	$18.75
Track, 10% of $36,000	3,600	18.00
Grading, 20% of $10,000	2,000	10.00
Bridging, 20% of $2,500	500	2.50
Miscellaneous, 20% of $5,000	1,000	5.00
Land, 20% of $15,000	3,000	15.00
Total	$13,850	$69.25

Assuming that 3,000 cu. yds. of sand and gravel are produced daily, half of which is sand, for which there is no market, we have the following cost:

	Per day.	Per cu. yd. of gravel.
Operating expense	$250.00	$0.167
Plant and land depreciation	69.25	0.046
Plant interest (at 5% of $93,500)	23.35	0.015
Total	$362.60	$0.228

This does not include the cost of stripping the gravel which was about 6½ cts. per cu. yd., making the total cost of this washed gravel nearly 30 cts. f. o. b. cars.

For description and drawings of this Pleasant Lake washing plant, and for hints on ballasting, see *Engineering-Contracting*, April 14, 1909.

Cost of Ballasting, Using Dump Cars.—The Goodwin steel car is largely used by contractors, and railway companies, for ballasting and for dumping earth and rock on standard gage tracks. Its dimensions are 36 ft. long, 9 ft. ¼ in. height above rails, and it weighs 47,500 lbs. Its capacity is 40 cu. yds., or 80,000 lbs. A train of cars can be dumped at one time all together, or one at a time, by one man operating a compressed air valve, or they can be dumped by hand. The car is so designed that its load may be placed between the rails; on either side of the track, or on both sides, or in any combination of ways desired. In grading and ballasting 22 miles of track with 30,000 cu. yds. of gravel, during the winter of 1904-5, an average train of 8 40-cu. yd. Goodwin cars was used, the average haul being 14½ miles. The gravel came from the pit quite wet, but required little or no spreading as plows and scrapers are not needed when these cars are used.

Mr. W. B. Stimson, Superintendent Grand Rapids & Indiana Ry., gives the following data on the loading and hauling of gravel for ballast:

Rodger ballast cars were used, working two trains of 25 cars per train. Sixteen miles of track were ballasted with 1,039 carloads, or 20,800 cu. yds. of gravel, or 1,300 cu. yds. per mile, the average haul being 7 miles. The cost was as follows for the 16 miles:

	Total.	Per day.
Two train crews, 12 days each.........$	175.00	$14.58
Locomotives, enginemen and watchmen.	199.25	16.60
Fuel for locomotives..................	254.10	21.17
Telegraph operator	15.50	1.28
Pit foreman	28.84	2.40
Pitmen	100.35	8.36
Steam shovel, including rent of shovel, fuel and wages....................	323.52	26.96
Total, at 5.3 cts. per cu. yd........	$1,096.56	$91.35

In addition to this it cost 6.7 cts. per cu. yd. to spread and tamp the gravel in the track, each laborer averaging 75 ft. of track per day. Including in the expense of 5.3 cts. per cu. yd., is the cost of moving the two trains and the steam shovel 166 miles to the pit, and half a day's time setting up the shovel and getting ready to work; so that the actual working time of the shovel was only 10½ days, making an average of 2,000 cu. yds. loaded per day of 12 hrs. The depth of the face at which the shovel worked was only 8 ft. The above is an exceedingly low cost.

The Rodger ballast car is 8 ft. 9 ins. x 34 ft. over sills, weighs 28,000 lbs. and its capacity is 60,000 lbs., or 20 cu. yds. of gravel heaped measure. The car is hopper bottomed, with plows and scrapers for spreading the ballast. One car is dumped at a time and fills about 80 ft. of track.

Cost of Rock Ballast.—The Railroad Gazette, Nov. 16, 1906, p. 438, gives the following cost of re-ballasting an Eastern railway:

	Per cu. yd.
Rock on cars at Rockland Lake................	$0.575
Floatage from Rockland Lake..................	0.086
Distribution by train (Rodger cars and ballast plow)	0.035
Labor putting in track........................	0.058
Total	$0.754

This does not include cost of preparing the old track, forking up old ballast, lifting track, etc.

It is estimated that $0.15 per cu. yd. would cover the added cost of putting rock ballast in a new track, including cost of lifting track, tamping, surfacing, etc.

Prices of Frogs and Crossings, Etc.—The prices used in estimating the cost of frogs, etc., on the New York Central, in 1902, were:

No.	Wt. of Rail, Lbs.	Description.	Price.
6	80	Rigid, Bolted	$27.00
10	80	Rigid, Bolted	32.00
10	65	Spring R.	48.50
8	60	Rigid, Bolted	23.00
8	65	Rigid, Bolted	24.00
8	75	Rigid, Bolted	28.50
Type A	80	Crossing Bolted	335.00 to 365.00
10	75	Spring R. Bolted	51.00
7	80	Rigid, Bolted	27.50
10	80 (5⅛")	Spring R.	49.25
10	67 (4½")	Spring R.	44.50
18	80 (5⅛")	Rigid, Bolted	45.00 to 70.00

Rail braces, 3.32 lbs. each, each	$ .10¾
Rail joints (80-lb. rail), Weber, insulated	5.25
Rail joints, Atlas, com.	3.75
Rail joints, 22-in. for 60-lb. rail	2.50
Replacers, Little Giant	15.00
Rail bender, roller	143.00
Rail chairs, cast, per 100 lbs.	2.48
Rail chairs, weights:	
4 ins. high, 19.5 lbs.	
3 ins. high, 18.6 lbs.	
Switch stand, Ramapo, low	10.00
Smoke jack in place	40.00
Track drill	18.00
Track jack	3.00

Cost of Track Scales.—On the N. Y. Central a 100-ton track scales, 42 ft. long, cost as follows, in 1902:

Scales and materials	$1,760
Labor	640
Total	$2,400
8.7 tons rails (relayers), at $20	174
15 ties, at $0.60	9
Miscellaneous material	150
Labor laying track, etc.	70
Grand total	$2,803

No piles were used in foundation.

The cost of 50-ton track scales, 42 ft. long, on the Northern Pacific, in 1899, averaged as follows:

Scales, delivered	$ 580
Other materials	170
Labor ($175 to $300)	250
Total	$1,000

The cost of 80-ton track scales, 50 ft. long, in 1905, was as follows:

Scales and materials	$1,250
Labor ($500 to $700)	650
Total	$1,900

Cost of Water Tanks.—On the Chicago & Northwestern, in 1896, the following was the cost of four different 50,000-gal. tanks, 16 x 24 ft., on 24-ft. posts:

TANK NO. 1.

Material:

Water tank, including hoops, etc.	$ 275
Two 8-in. standpipe	380
540 ft. 8-in. pipe, valves, etc.	315
1 bbl. pitch and 1 bbl. oakum	7
Posts, caps and braces	209
Stone, cement, etc., for foundation	309
108 ft. 4-in. gas pipe	22
Total material	$1,517

Labor:

Building tank	$ 263
Building masonry foundation	209
Painting tank, 2 coats	26
Laying pipe and setting standpipes	178
Total labor	$ 676
Grand total	$2,193

TANK NO. 2.

Material:

Tank, and posts, braces and caps	$ 304
One 8-in. standpipe	190
Two 8-in. gate valves	45
608 lbs. lead	21
660 ft. 8-in. cast-iron pipe	255
Lumber for well, pump house and standpipe foundation	23
80 ft. 4-in. gas pipe	16
Paint	20
Stone, cement, etc.	289
Total material	$1,163

Labor:

Building tank	$ 201
Building foundation	120
Laying pipe	199
Painting tank, 3 coats	35
Digging well (16 x 18) and walling it up	290
Total labor	$ 845
Grand total	$2,008

TANK NO. 3.

Material:

Tank	$ 275
One 10-in. standpipe	225
90 ft. 10-in. cast-iron pipe	72
Fittings for pipe and standpipe	65
Foundation for tank and standpipe	150
Paint	13
Total material	$ 780

(Posts, etc., seem to have been omitted.)

Labor:

Building tank	$ 238
Building foundation	133
Laying pipe	93
Painting, 2 coats	31
Total labor	$ 595
Grand total	$1,375

TANK NO. 4.

Material:

Tank	$ 304
10-in. standpipe	225
60 ft. 12-in. cast-iron pipe	72
Valves, elbows, etc.	65
2,586 lbs. lead, at 3⅜ cts.	87
250 pieces 6-in. cast-iron pipe	1,230
Paint	20
Material for standpipe	21
Material for tank	129
Total material	$2,153

Labor:

Building tank	$ 228
Laying 3,000 ft. pipe, at 30 cts.	600
Building foundation of tank	112
Building foundation of standpipe	18
Painting, 2 coats	29
Total labor	$ 987
Grand total	$3,140

The cost of a 16 x 24-ft. tank, on the C., R. I. & P., in 1896, was:

Tank with 12 hoops	$275
Indicator	5
Set 7-in. fixtures	68
12 iron post caps	24
Rail joists, at $5 per ton	19
Substructures (incl. frost proofg.)	198
Paint	15
Foundation stone	69
Labor erecting tank	165
Labor painting tank	24
Labor on foundation	116
Total	$978

On the Lehigh Valley Ry., in 1896, a 20-ft. tank cost as follows:

2,720 lbs. wrought-iron hoops, at 3 cts.	$ 82
4,560 ft. B. M. of 3-in. cypress for staves and bottom, at $28	128
700 ft. B. M. yel. pine (1 x 3) for false bottom, at $20	28
6,000 ft. B. M. white pine, at $30	180
Nails, door, ladder, etc.	30
56 cu. yds. masonry foundation, at $5.00	280
Lead, etc.	35
Labor erecting tank	175
Total	$938

On the Northern Pacific, from 1890 to 1900, the average cost of 25 tanks, 16 x 24 ft., was as follows:

Materials	$ 900
Labor	800
Total	$1,700

In no case does this include pump, pump house, well, etc., but it does include pipe, foundation, etc.

The cost of a typical water tank on the Erie Ry., in 1901, was as follows for a 50,000-gal., 16 x 24-ft. tank:

Tank and Substructure:	
16 x 24-ft. pine tub	$ 275
30,270 lbs. steel trestle, at $2.25	832
49 ft. iron ladder	13
9 squares slate for roof	27
9 squares tar paper	3
40 lbs. yellow metal slate nails	7
128 ft. galv. ridge roll	4
Pine	80
Nails, etc.	10
14 gals. paint	16
63 bbls. cement	86
30 cu. yds. crushed stone	12
31 cu. yds. sand	15
9,000 brick	63
Mason labor	239
Carpenter labor	187
Total	$1,869
Plumbing:	
Standpipe, 10-in., complete	$ 225
10.75 tons 10-in. cast-iron pipe	237
1 length (12 ft.) 10-in. flanged pipe	17
3 elbows (10-in.) and 1 sleeve (10-in.)	35
552 lbs. lead	24
130 ft. galv. pipe (3-in.)	47
1 Worthington meter (3-in.)	78
1 gate valve (3-in.)	4
1 angle valve (2-in.)	3
70 ft. sewer pipe (4-in.)	2
1 iron grating for drain pit	4
1 galv. iron float, beam and chain	4
4 pr. pipe flanges (3-in.), etc.	5
6 nipples (3-in.), 4 elbows and 1 tee	2
Labor of plumbers	153
Total plumbing	$ 840
Grand total	$2,709

Cost of Track Tank.—The form of track tank shown in Fig. 9, 1,200 ft. long, on the B. & O. R. R., cost as follows, in 1890:

Repairing roadbed	$ 1,094
Labor placing trough and pipe	2,135
Trough, including shop work	4,159
Cross-ties, pipe and other material	2,936
Hauling	61
Total	$10,385

The trough was of steel 3/16 in. thick, made in 30-ft. sections.

The above cost includes 75 ft. of 8-in. cast-iron pipe and two standpipes for use of freight engines.

The cost of operating such a track tank was as follows per month:

Two pumpmen, at $45.00	$ 90.00
15 tons coal, at $1.50	22.50
Ordinary repairs	20.00
Total	$132.50

Examples of Practice in Turntable Construction, With Some Data on Costs.*—The following text consists of a series of letters discussing seven subjects suggested by a committee as follows:

(1) Proper length, allowing for probable future increase in length of locomotives. (2) Plate girder tables, and cost. (3) Cast-iron tables, and cost. (4) Gallows frame tables, and cost. (5) Other designs, and cost. (6) Foundation, circle wall, paving if any and pit drainage. (7) Power for operation; electricity, air and other power.

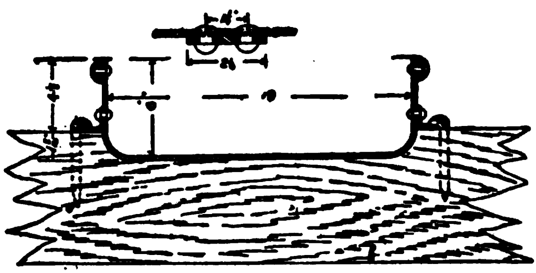


Fig. 9.—Track Tank.

J. P. Canty, Boston & Maine R. R.—Anticipating the probable length of a turntable required for future locomotive service, is rather an uncertain problem just at this period. However, it is the opinion of many that, on the division where I am located, the lately purchased steam locomotives have apparently reached their economical limits in both length and weight, provided the class of traffic remains similar to that which is now being handled.

The largest engines on our division are turned easily on turntables 70 ft. long. This is now our standard length, and as far as we are able to predict, will answer for future requirements.

The steel work in these tables cost approximately $2,500 on board cars delivered to our road by the contracting bridge company. There is nothing unusual about the design. However, I will mention that we specify that four cast steel end wheels shall be furnished on each end of table and the center pivot bearing shall be of the disc pattern; meaning that the table turns on a composition disc on top of the center cast steel pivot casting, instead of on the familiar roller bearing.

**Engineering-Contracting*, Oct. 27, 1909.

Our turntable center foundations have, of late, been made of concrete, being 10 x 10 ft. on bottom and bearing on piles when there is doubt about the earth being sufficiently solid to carry the maximum load on this area without settling. The bottom course of concrete is generally 2 ft. in depth. The foundation is then stepped 7½ ft. square by 2 ft. thick, and a granite cap 5 ft. square by 2 ft. in depth is placed on top to receive the cast steel center pedestal.

There are 330 cu. yds. of masonry in our 70-ft. turntable pits. The whole outfit, including turning motor, costs us between $6,000 and $7,000. Figures vary for different locations, depending upon whether or not we are obliged to drive piles, provide expensive drainage, etc.

Practically all of these new outfits have been put in where older and smaller tables were installed and as the older tables were kept in service just as long as possible so as to avoid delays to engines, our work has always been made more expensive than if new tables were constructed where we would not be handicapped by keeping the old table in use.

We use gasoline power turning device.

The floors of the turntable pits are covered with a coal-tar concrete paving, about two and one-half inches thick, somewhat similar to that which is used extensively in small cities and towns in New England for sidewalk surfaces. This gives a fairly hard and elastic surface, and does not crack when soil underneath heaves with frost, and is comparatively smooth, so that it is easily kept clean and snow may be removed from pit without much trouble. The cost is about 50 cts. per sq. yd.

A. H. Beard, Philadelphia & Reading Ry.—The cost of our plate girder standard 75-ft. table in place ready for the track rails is $7,785.00, as follows:

Masonry	$2,500.00
Miscellaneous	500.00
Table	4,785.00
	$7,785.00

A 65-ft. plate girder table has been in service at the roundhouse at Reading since 1897. This was manufactured by the Pottstown Bridge Co. Engines of all classes are turned on this table, the number turned every 24 hrs. (although the table is short for some engines) is 75 to 80. The cost of this table in place was $5,825. This table at present is operated by an 8-hp. gasoline engine, manufactured by the Williamsport Gasoline Engine Co., the cost of same in place was a fraction over $1,000, and costs for operating about $165 per month, this includes labor, oil, gasoline and repairs; we are now arranging to install an electric motor on the same table to replace the gasoline engine.

E. E. Schall, Lehigh Valley R. R.—Our 80-ft. turntable is constructed as follows: Deck plate girders 5 ft. 6¼ ins. deep at center and 2 ft. 8¼ ins. at ends, spaced 6 ft. c. to c., conical wheel center bearings with live ring, built for a moving load of Cooper's

E. 50 engines or 4,500 lbs. per lin. ft. of table. Cost about $3,200 delivered f. o. b. cars within 200 miles of bridge shop.

The center foundations and circular rim walls are generally of concrete, the circular rail resting on short sawed ties. The top of rim is covered by a white oak timber coping to act as a cushion with rail tie-plated. The pit is paved with concrete about 6 ins. thick, and provided with drainage. For outlying districts, and tables not used extensively, the rim wall is at times omitted, using only a segmental wall at entrance and run-off of table, using ballast under the ties of circular rail.

For operation we have in use electric motors, gasoline engine motors and air motors; all are giving satisfaction. When electric power is at hand, it is the most suitable power to use; when electric current must be purchased from other parties or when none is available, gasoline engine motors of from 8 to 10 hp. will prove very satisfactory. The air motor will also prove efficient if properly installed and arranged to take proper adhesion on circular rail, obtaining a sufficient supply of air from locomotives to be turned, unless the air can be taken from a compressor near by. The air motor will not turn as many engines in a given time as either of the other two kinds, on account of the time required in making couplings, but for outlying districts it is the best motor attachment available at this time. The cost of installing one of the motors ranges from $900 to $1,200.

A. A. Wolf, Chicago, Milwaukee & St. Paul Ry.—We use 85-ft. turntables on mountain division where the heaviest power is used, and 75-ft. tables on other main line divisions. We have three types of the plate girder tables, which we distinguish as through, semi-through and deck. The reason for these various designs is occasioned by the difficulty in many places of getting drainage from the pit to a sufficient depth to accommodate a deck table. These plate girder tables cost from $6,000 to $8,500, varying somewhat with local conditions, pertaining to the nature of foundations, etc. The labor amounts to from 35 to 40% of the total cost.

For plate girder tables, we use a concrete center pier, circle wall and circle rail foundation; the circle wall and foundation for circle rail being of monolithic construction. Piles are always used under center foundation, except at places where solid ledge rock is found. Piling is used under circle wall except where rock or other firm soil is found. We do not make it a practice to pave the pits. Drainage is provided by means of connection to roundhouse sewer or to low adjacent ground, according to local conditions.

We use gasoline and electric motors only for power; the electric motor, in our estimation, furnishes the ideal power for turntable operation where it can be procured without excessive cost. At several of our division points we have our own generators and consequently the current required for operating turntable costs but very little.

I. O. Walker, Nashville, Chattanooga & St. Louis Ry.—Our stand-ard length is 70 ft. Plate girder tables cost with ties, latches, etc.,

in place, $3,200. Masonry and foundations $2,000. The cost of the masonry is extremely variable, however.

W. T. Main, Chicago & North Western Ry.—Turntables newly installed in the future should be 80 ft. in length. A 70-ft. King Bridge Co., deck plate girder turntable installed at Chicago Ave., in 1907, cost as follows:

Material	$2,570.46
Labor	2,262.00
Total	$4,832.46

This table replaced an old 60-ft. deck plate girder and was installed under continuous traffic except for two days while new concrete center pier was allowed to set. Over 400 engines were turned every 24 hrs. on old table during construction of new circle wall which will give some idea of conditions under which work was done and reason for high cost. Table is operated by 10-hp. electric motor which was used on an old table but furnished with new frame. A 70-ft. King Bridge Co., deck plate girder turntable installed in 1907 cost as follows:

Material	$2,890.00
Labor	2,262.00
Total	$5,380.00

This table replaced an old 60-ft. Lassig plate girder and was installed under traffic in same manner as the one before mentioned. About $500 of the cost was due to renewal of radial tracks. The circle wall was built of concrete and the center pier of concrete, reinforced with scrap rails in order to spread the load over old masonry foundation. The table is operated by 10-hp. Pilling air motor and has six reservoirs under runways, the air being furnished by air compressor.

A 60-ft. Stroebel deck plate girder table installed at Chicago Ave., in 1899, on old masonry wall and new center pier, cost $2,500. A 60-ft. Greenleaf cast-iron table installed at Milwaukee, 1899, including new center pier, cost $3,100; the table alone cost $1,160. A 50-ft. gallows frame turntable installed at Evanston in 1896 with timber circle wall and center pier cost $983.

Circle walls should preferably be built of concrete except when table is renewed under traffic, where rubble masonry can be used to better advantage while working in cramped space. Center pier may require pile foundation unless subsoil is good, where a spread foundation of concrete or masonry 12 ft. square will serve. The advantage of paving in pit will hardly justify the additional expense though it is easier to keep pit clean when paved and helps the drainage. The best drainage possible should always be secured. Circle walls should have an offset at one point to allow of examination and repairs to end rollers and boxes, particularly where table has rollers between girders. Masonry circle rail seat should be extended at two points, diametrically opposite, to afford support for jacks for raising table and examining center. This saves placing cribbing

on soft ground when using jacks and renders the operation much safer.

Would recommend the use of electric motor for operating table wherever possible and where service demands the quick handling of engines; second choice, gasoline engine; third choice, air motor. The latter gives excellent service, where there is plenty of time for handling engines and where there is sufficient supply of compressed air which can be piped to reservoirs, but it is slow in operation where engine to be turned must supply the air.

A. O. Cunningham, Wabash R. R.—No table less than 75 ft. should be used. Deck tables of this length cost $2,600. The foundation of circular wall and paving should always be of concrete; pit should be well drained; the cost of this for 75-ft. deck table would be $3,700.

Electricity is the ideal power for operating a table. If this cannot be obtained a gasoline engine may be employed of about 6 hp. The cost of the electrical equipment would be $1,150, and for the gasoline engine equipment $1,000.

W. H. Moore, New York Haven & Hartford R. R.—The standard length for turntables on our road is 75 ft., but we build some tables 80 ft. long. The approximate average cost for a 75-ft. deck plate girder turntable is about $3,500, and for a half through plate girder turntable about $5,750. The cost of foundation of the circular wall, etc., varies so much, depending on the nature of the ground, that it would be hardly proper to name any average. I may say, however, that for a concrete pit with granolithic floor and granite center stone, in a location where there was good firm sand requiring no piles and where drainage could be cheaply taken care of, the total cost is about $3,800. For power operation we use mostly gasoline motors; some air motors, and electric motors where current can be conveniently obtained. The cost of power installation averages about $1,000.

G. Aldrich, New York, New Haven & Hartford R. R.—For the requirements of modern engines, 75-ft. minimum; 80-ft. recommend; 75-ft. deck plate girder, erected complete $3,600, base of rail on table to top of center pier, 6 ft. 4 ins.; base of rail on table to top of circular rail, 4 ft. 8 ins.; 75-ft. through plate girder, cost with floor erected complete, $5,750. Base of rail on table to top of center pier, 3 ft. 11 ins.; base of rail to top of circular rail, 2 ft. 9 ins. The foundation, circular wall and center pier are constructed of concrete; the pit is usually paved with granolithic pavement. The cost varies in accordance with local conditions, ranging from $2,500 to $4,000.

For power we use: (a) air supplied by the engine being turned; (b) air supplied from compressors in adjacent shops; (c) gasoline engines; (d) electric motors. Electric motors preferred where current is available; air motors, supplied by compressors, second, and gasoline motors third choice. The cost of power installation varies from $900 to $1,200.

N. F. Helmers, Northern Pacific Ry.—The Northern Pacific Ry. are installing 80 and 85-ft. tables. I do not anticipate any power

in the future which will call for the use of a larger table. An 80-ft. through table, without the circle rail, and weighing 114,855 lbs., cost in place $4,600. Such a table was installed at Staples, Minn., with concrete circle wall and center foundation. The masonry was done by contract, and the installation of the table by the company at an expense of $3.92 per ton. The framing of ties and other timber cost $4.05 per thousand feet. The cost was as follows:

	Labor.	Material.
Turntable	$211.44	$4,198.52
False work	.....	12.93
Timber, ties, planking, etc.	35.23	77.49
Painting	27.49	44.78
	$274.16	$4,333.72
Total cost (not including masonry)		$4,607.88

In 1908 an 80-ft. table of the same type was installed at Minneapolis replacing one 64 ft. in length. The foundation work was done under traffic, and the change of tables was done with a total interruption of 15 hrs.; itemized statement follows:

	Labor.	Material.
Excavation	$ 463.94	....
Gravel	92.14	....
Concrete work	408.28	$ 651.52
Forms	21.76	134.19
Circle rail	38.74	....
Table proper	361.36	4,040.95
False work for curbing	......	66.36
Removal of old brick curbing	104.42	....
Cleaning girders	37.98	....
Painting	23.76	21.04
Ties and coping	79.71	188.89
Engineering	......	14.66
	$1,632.09	$5,117.61

The total cost was $6,749.70.

I consider that ordinary conditions do not require the necessity of paving for the pit, but good drainage is essential in most cases.

For power we are using electricity and compressed air, while some of the 80 and 85-ft. tables are being turned by hand. Air motor in use at Jamestown, N. D., cost at St. Paul, $450; installation, $19.81; total, $469.81. Electric tractor furnished by Nichols & Bro., cost $1,104.37; installation, $115.86; total, $1,220.23.

W. T. Powell, Colorado & Southern Ry.—The up-to-date table should be 80 ft. long, with a capacity for turning 200-ton engines. We installed recently an 80-ft., 200-ton, through-plate girder table which cost as follows:

Table f. o. b. Denver, including circle rails	$3,700.00
Material for concrete foundations and walls	1,090.00
Labor	1,600.00
Total cost	$6,390.00

This table replaced a 66-ft. table and we were compelled to excavate and put in the curbing under 42 tracks and keep them safe

while in use. We drove 24 piles for center foundation and capped it with a block of concrete 12 ft. square and 4 ft. thick; a deck table of this length and capacity would cost about $600 less. We use concrete entirely for masonry; rails are fastened with bolts and cast clips, the bolts being set in the concrete; no paving; drained when necessary. We use air power with a two-cylinder motor.

J. S. Browne, New York, New Haven & Hartford R. R.—We have recently installed an 80-ft. table at Providence. The center pier is of concrete, reinforced with steel rails, on account of the irregularity of the supporting material, as it was feared that the concrete might be fractured by the load if laid without reinforcement. The outer wall of the pit and the paving are also of concrete.

While an accurate record was not kept of the cost it was approximately as follows:

80-ft. steel table delivered at Providence	$3,400.00
Placing coping and circular rail and moving table into pit	800.00
Concrete in outer wall and center, including forms	2,800.00
Excavation, including disposal of material	1,500.00
Paving	300.00
Drain pipe to connect with sewer	200.00
Total	$9,000.00

The work was done by the company's force, and the high cost of excavation was due to the fact that a portion of the work was done in freezing weather, and it was necessary to handle the material more than once before its final disposal by work trains.

The company's standard main line turntable is 75 ft. long, but 80 ft. is considered better at points where the largest type engines are turned, to permit of properly balancing them. Deck plate girder tables are used where sufficient depth is available without excessive cost, but where this is not feasible, half through plate girder tables are used. The superstructure of deck tables is about 30% cheaper than that of half through tables, but this saving is balanced by the greater cost of the pit, so that under ordinary conditions the total cost of these two types is about equal. Gasoline motors are generally used for power, although electric motors may be used to considerable extent in the future.

J. N. Penwell, Lake Erie & Western R. R.—On our main line, we are taking out 62-ft. tables and replacing with 80-ft. tables, using the old ones on the branch lines. We have two of the old cast-iron tables, 50 ft. in length, which have been in use 20 yrs., one of which is in perfect condition and the other about worn out. We have only one of the old style gallows frame tables, but it is out of date and will be replaced with a more modern structure within two years. For the foundation and circle walls we are using concrete. If foundation is not absolutely reliable, we drive piles. Drainage is important and the very best should be provided. Our tables are all operated by hand, except one which we are now operating with air. Would recommend electricity wherever it can be had. In erecting new tables we make provision for air pipes in the foundation, so that we can use air in the future if we desire.

Cost of Turntables.—The following was the estimated cost of turntables for the N. Y. Central Ry., in 1902:

Size of Turntable.	70 ft.	75 ft.	80 ft.	85 ft.
Turntable delivered, f. o. b....	$1,965	$2,400	$2,600	$2,800
Labor erecting	395	430	460	500
Pit	3,600	3,800	4,000	4,200
Mortar for turning...........	900	900	900	900
Total	$6,860	$7,530	$7,960	$8,400

Cost of Ash Pit.—On the Northern Pacific a standard ash pit with brick side walls and concrete bottom was built at a cost of about $9 per lin. ft. in 1890. The width between the side walls is 4 ft., and the clear depth of the walls is 3½ ft. below top of rail. The brick side walls are 17 ins. thick. The sides of the pit are protected by cast-iron plates, ½ in. thick, 18 ins. wide, and 3 ft. 4 ins. long. The bottom of the pit is paved with hard brick set on edge and bedded on 8 ins. of concrete. This concrete foundation extends under the side walls where it is thickened to 12 ins. for a width of 2 ft.

On the N. Y. Central in 1902, the following was the cost of different types of ash pits:

Elevated ash pit, $13 per lin. ft., plus $39 for the two ends.
Semi-depressed pits on the main line, $20 per lin. ft.
Ditto, for minor pits, $15 per lin. ft.

Cost of Snow Sheds.—On the Northern Pacific R. R. (in 1890) the standard snow shed on level ground consisted of timber bents (8 x 10-in.), 6 to 10 ft. apart, to which were fastened horizontal studding (4 x 10-in.), and to the studding was spiked 2-in. upright siding. The roof was double-pitched, with rafters 4 x 10-in., and sheeted with 2-in. plank. For wet snow, the bents were spaced 6 ft. apart, requiring 304 ft. B. M. and 13.3 lbs. of iron per lin. ft. of snow shed. At $30 per M, and 5 cts. per lb., the cost was not quite $10 per lin. ft. of shed.

The standard snow shed in through cuts (single track) has bents 6 ft. apart, and it requires 484 ft. B. M. and 14 lbs. of iron per lin. ft., the cost being $15 per lin. ft.

A standard side-hill snow shed, with a flat roof, with bents 6 ft. apart, contains 634 ft. B. M. and 10 lbs. of iron per lin. ft., costing $20 per lin. ft.

None of the foregoing have any cribwork, being entirely sawed timber. Nor is any extra excavation involved in their construction. These sheds are not designed to resist snow slides or avalanches.

In Trans. Am. Soc. C. E., Vol. 29, 1888, Mr. Thomas C. Keefer has described and illustrated the types of snow sheds built (1887) in the Selkirk Mts., on the Canadian Pacific Ry. Fifty-three sheds. total 7 miles long, were built.

The typical "avalanche shed" has a log, rock-filled crib, forming a retaining wall back of which is an earth fill. This forms the uphill side of the shed. The roof and downhill side are of sawed timber. The cost ranged from $40 to $70 per lin. ft. of "avalanche shed."

Where cribwork was not needed, "gallery sheds" were built at a cost of $15 to $40 per lin. ft.

Cost of Snow Fences.—The standard portable snow fence of Chicago, Milwaukee & St. Paul has the following bill of material for a panel 16 ft. long:

Legs, 3 pieces 2 x 6-in. x 14-ft., No. 1 Common.
Boards, 11 pieces 1 x 6-in. x 16-ft., No. 2 Fencing.
3 carriage bolts, ½ x 5 ins.
3 No. 10 = 0.1 lb.
66 wire nails, 8d. = 0.5 lb.
60 wire nails, 10d. = 0.7 lb.

When stakes are used to hold the legs down, use 6 stakes cut from 2 x 4-in. x 2-ft. No. 1 common ripped diagonally, and fastened to the legs with a total of 12 wire nails (20d.).

When ground is frozen, use drift bolts instead of stakes, using 6 drift bolts (½ x 15-in.) and 12 wire staples (3-in.).

This fence contains 130 ft. B. M. per panel 16 ft. long, and weighs 327 lbs. when made of green lumber. In 1899, the cost was $1.60 per panel, f. o. b. cars, complete with stakes and spikes.

On another Northwestern railway, the cost per 16-ft. panel was:

126 ft. B. M., at $15, incl. nails	$1.89
Labor	0.11
Total	$2.00

On another road the cost per 16-ft. panel was:

152 ft. B. M., at $17	$2.58
Nails	0.10
Bolts	0.05
Labor	0.35
Total	$3.08

On the C. & N. W. Ry. a stationary snow fence is largely used. Cedar posts, 12 ft. long, are set 4 ft. in the ground and 8 ft. apart. The boards are 1 x 10-in., spaced 2 ins. apart, leaving an open space of 12 ins. next to the ground. The cost of this fence per 16-ft. panel was as follows, in 1900:

96 ft. B. M. boards, at $14.50	$1.39
2 cedar posts, at 30 cts.	0.60
1½ lbs. 10d. nails, at $2.40	0.04
Labor	0.60
Total	$2.63

For costs of right of way fences see the index under Fences.

Cost of Mail Cranes.—On the St. Louis & Southwestern Ry., in 1902, the standard mail crane cost:

Crane and materials	$13.00
Labor	6.35
Total	$19.35

This was a wooden mail crane. A common cost of wooden mail cranes is $12 to $15, erected in place. Iron mail cranes cost about $35 in place.

Cost of Interlocking Signal Plant and of Operation.—Mr. J. A. Peabody estimates that the average interlocking plant will have a life of 20 yrs., but, to be on the conservative side, assumes 15 yrs. He estimates such a plant will cost $8,000, including cross-over, 4 derails, 4 high signals and 6 dwarfs.

To operate and maintain this plant would cost:

	Per year.
Interest, 4% of $8,000	$ 320
Depreciation, 7%	560
Maintenance, 10.5%	840
Operation	1,440
Total	$2,800

He estimates that where there are 17 trains stopped daily, at a cost of 45 cts. per stoppage, the yearly cost is $2,800 for stopping trains. Any greater number of trains would justify an interlocking plant merely to save the expense of stopping trains.

See *Engineering-Contracting*, February, 1906, p. 49, for Mr. Peabody's complete discussion.

Definition of "Mile of Railway."—In discussing railway costs per "mile," there is great danger of confusion, for there are three kinds of "miles of railway": (1) The mile of roadbed, equivalent to the mile of right of way; (2) the mile trackway, including all 1st, 2d, 3d and 4th tracks upon which trains travel regularly between stations; and (3) the mile of track, including all tracks of every nature, main, branch, side tracks, yard tracks, etc. Due to the different meanings assigned to the "mile of railway," I have abandoned the use of that term, and for this book I have adopted the three terms above used: (1) Roadbed, (2) trackway, and (3) track.

The Interstate Commerce Commission uses the word "line" when referring to "roadbed."

Many engineers use the word "line" when referring to "roadbed."

The term "main line" is also ambiguous, as many people use it to include "branch" lines.

The word "branch" has no definite meaning, as a rule, and refers merely to lines having a light traffic, and generally to lines that branch from the main line and do not carry "through traffic."

"Spurs" is another ambiguous term. A short branch line, especially one that serves only one class of traffic, is commonly called a spur.

Logging "spurs" are often merely temporary lines, too long to be called "sidings," and yet not of a character worthy of being designated as branch lines.

"Sidings" are short lengths of track at stations, where trains pass, and where cars await loading and unloading; also short tracks

serving factories, mills, etc. Sidings merge into "yard tracks" at large stations.

Average Cost of Railways in America.—Many generalizations founded on meager data have been made as to the probable average cost of American railways. The Interstate Commerce Commission receives annual reports from all railways, and those reports give the "cost of road." The last report of the Commission, for the year 1906, gives the following as the total of all roads, taken from the general balance sheets of American railways:

Cost of road	$11,588,922,421
Cost of equipment	831,365,517

Neither of these figures means what it seems to mean.

The following was the total mileage:

Single track (= roadbed)	222,340
1st, 2d, 3d and 4th track (= trackway)	243,322
All tracks, including sidings, etc.	317,083

According to this, the "cost of road" would be $50,200 per mile of roadbed, and cost of equipment would be $3,740 per mile of roadbed. The first is too high and the second is too low. The "cost of road" is, in large part, the *price* paid for it by its present owners; and, as nearly all American roads have changed hands at least once, it is evident that this *price* is more nearly a function of *value* based on net earnings than it is a function of actual cost of construction.

The "cost of equipment" is far below the actual cost of new equipment, since most roads report the depreciated or second-hand cost of equipment. Indeed, it seems that some roads report merely a nominal cost of equipment to escape taxation.

The capital stock and funded debt (= bonds) reported for 1906 was as follows:

Funded debt	$ 8,068,004,746
Capital stock	6,929,670,224
Total	$14,997,674,970

From this it follows that the following stock and bonds were outstanding per mile of roadbed:

Funded debt	$36,300
Capital stock	31,200
Total	$67,500

Since nearly all American railways have been built with money secured by the sale of bonds, it is evident that the average American railway (including equipment) has cost at least $36,300 per mile of roadbed. The capital stock largely represents the capitalized value of the net earnings, although in some instances it represents money actually expended in construction and equipment.

Of the $75,458,000 spent in building and equipping the 1,645 miles of the Northern Pacific Railway in Washington, $8,848,000 was ex-

pended for improvements (exclusive of equipment) since the original construction. If this is typical of average expenditures for railway improvements throughout America, it would be necessary to add about 10% to the $36,300 above given, which would make the average cost of construction and equipment about $40,000 per mile. It has been the common practice to make most improvements out of earnings, without issuing bonds; hence it is reasonably certain that American railways have actually cost at least $40,000 per mile of roadbed for construction, land and equipment. Nor do I believe that this cost has been much exceeded. On the other hand, the cost of reproducing the same roads to-day would probably exceed this sum, and might exceed it very much, the reason being that land values have appreciated so greatly since the roads were built. This is well brought out elsewhere in this book where the original costs and costs of reproduction of Washington railways are given.

Cost of Railway Lines.—In Engineering Magazine, December, 1895, Mr. J. F. Wallace gives the following estimates of the average cost per mile of single track roadbed in the United States:

Class of Railway.	A.	B.	C.
Right of way	$ 1,000	$ 1,500	$ 2,000
Proportionate expense of terminals	500	1,500	5,000
Bridges and culverts	1,500	2,500	4,000
Grading	3,000	6,000	12,000
Track laid	6,000	6,500	7,000
Ballast (rock)	.....	2,500	3,000
Fencing	300	400	400
Telegraph	200	250	250
Stations and water supply	500	800	1,200
Engineering	400	500	700
General and legal expenses	200	400	600
Equipment, cars and locomotives	1,500	2,500	4,000
Total	$15,100	$25,350	$40,150

Class "A" is a branch line, 2 passenger and 4 daily freight trains.

Class "B" is a secondary line, connecting small cities.

Class "C" is a trunk line, 90-lb. rails.

It will be noted that the item of "Engineering" is considerably below what it actually cost the various railways in the state of Washington. See pages 1303, 1306 and following.

In fact, Mr. Wallace is low, in my judgment, on nearly every item enumerated, excepting, perhaps, general and legal expense.

Cost of a Mining Railway.—Mr. John H. Pearson gives the following cost of The Winchester & Beattyville R. R., built in 1893. The road is 8 miles long, and has 9 miles of track including sidings. It was built to open up a mining district, and it runs through rugged country. No grades exceed 1%, and the maximum curve was 6°, except two 12° curves. The cost per mile of roadway (8 miles) was as follows:

		Per mile of roadbed.
1.	Preliminary surveys	$ 19
2.	Locating surveys	111
3.	Engineering during construction	375
4.	Stationery	28
5.	Office furniture	6
6.	Tools	83
7.	Grading roadbed	2,233
8.	Trestles (at $23 per M in place and iron at 5 cts. per lb.)	1,393
9.	Culverts	159
10.	Legal expenses	10
11.	Right of way	428
12.	Cross ties (31 cts. each) and handling	696
13.	Rails (56-lb. relayers, at $25 per ton)	2,370
14.	Track fastenings	506
15.	Switches	140
16.	Ballast (1,000 cu. yds.)	330
17.	Fences and cattle guards	41
18.	General expenses	220
19.	Tracklaying and surfacing and repairs	988
20.	Water station ($1,380)	172
21.	Depot and other buildings ($1,320)	165
22.	Engines, cars and repairs ($6,013)	752
23.	Fuel, oil and waste	83
24.	Conducting transportation	321
25.	Telegraph line	.....
26.	Three coal and lumber switches	2,021
	Total	$13,650
	Net revenue from operation ($6,000)	750
	Balance	$12,900
	Deduct equipment	714
	Total cost of construction	$12,186

Since there was 1 mile of side track to 8 miles of roadway, the above costs should be divided by 1.125 to arrive at the cost per mile of track. Multiplying by 0.9 will give almost the same result.

Wages were low at that time, common laborers receiving $1.25 a day; teams, $3.50; single mule and driver, $1.75; foremen, $2.00.

Cost of a Logging Railway, Pennsylvania.—Mr. William Barclay Parsons, in Trans. Am. Soc. C. E., Vol. 25, p. 119, briefly describes the location and construction of 7 miles of standard gage logging railroad built in Northwestern Pennsylvania in 1890. The maximum curve was 18°, and the ruling grade, 3.3%. The country was heavily wooded with hemlock and very rough; clearing and grubbing costing $50 to $60 an acre for a right of way 50 ft. wide. Cuts were 16 ft. wide and fills 12 ft. Log culverts were used under banks 10 ft. or less in height. The excavation averaged nearly 11,000 cu. yds. per mile, of which 7.6% was rock, 11% loose rock, 35.2% tough clay (1 pick to 1 shovel), and 46.2% earth, most of which was heavy soil. The clearing and grubbing, log culverts and excavation when charged up to the excavation cost 46½ cts. per cu. yd., or about $5,000 per mile. (The excavation alone probably cost about 40 cts. per cu. yd. The toughness of the earth and the presence of roots made the excavation expensive. Wages were prob-

ably $1.25 per 10-hr. day.) The cost of one mile of finished road on the heaviest part of the line was as follows:

62.86 tons of 40-lb. rails, at $33.00	$2,074.38
352 joints complete, at $0.55	193.60
6,200 lbs. spikes, at $0.0225	139.50
3,000 cross ties, at $0.15	450.00
Freight on materials	159.00
Tracklaying	400.00
Grading	5,026.89
Trestles (at $17 per M in place)	250.45
Surveys, inspection, etc.	400.00
Total per mile	$9,093.82

Cost of a Short Branch Line, Texas.—In 1903 a first-class branch line was built in Texas to give the St. Louis Southwestern an entrance into Dallas. The line is 12.13 miles single track and has 1.52 miles of sidings, total 13.65 miles of track. The line is almost entirely tangent, and follows a ridge.

	Total.
Engineering	$ 6,323
Grading	48,924
Bridges, trestles and culverts	41,061
Ties	26,838
Rails (75-lb.)	37,607
Track fastenings	5,596
Frogs and switches	1,177
Ballast	30,526
Tracklaying and surfacing	9,511
Crossings, cattle guards and signs	1,929
Total	$210,092

It will be noted that land and equipment are not included, nor interest during construction.

Engineering cost about 3%, and tracklaying and surfacing cost about $700 per mile of track.

Cost of a Cheap Railway, Georgia.—Mr. A. Pew, in Trans. Am. Soc. C. E., Vol. 23, in a paper entitled "The Cheapest Railway in the World," gives the following as the cost of a 19-mile railway in Georgia:

Cost per mile of road and track	$3,440
Cost per mile for equipment	1,000

The roadbed was only 10 ft. wide in fills and 14 ft. in cuts, and the excavation averaged 4,000 cu. yds. per mile. The excavation cost only 9 cts. per cu. yd., wages of laborers being $1 per 10-hr. day. The ties cost only 10 cts. each, and 45-lb. rails were used.

Report of H. P. Gillette to the Washington Railroad Commission on the Valuation of the Railways.*—Before explaining the methods pursued in making the appraisal, it is as well to record the fact that the state of Washington is the first state in the Union to complete the valuation of its railways for the express purpose of using these values as a basis for rate making. Only one other State

*_Engineering-Contracting_, April 7, 1909.

Railway Commission takes priority over the Washington Railroad Commission in point of time of completing a valuation of the railways within the state, namely, the Texas Railway Commission; but it should be remembered that the object of the valuation of the railways of Texas was not for the purpose of rate making, but for the purpose of limiting the issues of stocks and bonds—that is, to prevent "stock watering"—which presents quite a different problem from that presented to the Washington Railroad Commission. Vastly greater interests are at stake than when railway values are to be used merely to limit the issue of stocks and bonds of railways chartered within the state. Hence, both the scope of my investigation of railway values, and the methods used were radically different and necessarily much more complex than prevailed in the Texas appraisal. For example, in the following out of the requirements of the Washington statute, you felt impelled to secure all the data enumerated by the Supreme Court of the United States in the celebrated Nebraska rate case known as the Smythe v. Ames case. The Supreme Court held in its decision of that case that a rate-making body must consider, among other things:

First. The original cost of the railway, plus improvements and betterments.

Second. Its cost of reproduction new.

Third. Its present value, ascertained by deducting its depreciation from its value new.

Prior to this Washington railway appraisal, no railway commission in America had ever attempted to comply with the decision of the Supreme Court in the Nebraska case, and I believe that all the failures on the part of other railway commissions in their rate-making efforts may be traced directly to their fundamental failure to follow the Nebraska rate case decision. Flat rate making has proven abortive, because of attempts to make rates without full knowledge of all the factors which the Supreme Court has held to be necessary in forming an intelligent judgment; and prominent among these factors are the original cost, the cost of reproduction, and the present value.

Two other states besides Texas have made railway appraisals, namely Michigan and Wisconsin; but in neither of these instances was the appraisal made by a railroad commission. Both the Michigan and Wisconsin appraisals were made for the purposes of taxation, and were not governed by the Nebraska rate case decision.

The state of Washington is the first state to secure the *original cost* of the railways within its boundaries and is, therefore, the first state to investigate the accounting records of the railways with the object of ascertaining the actual original cost and the cost of improvements and betterments.

I mention this fact not merely for the purpose of putting on record the priority which the Washington Railroad Commission can justly claim in following the law as laid down by the Supreme Court, but for the purpose of making clear the magnitude of the task confronting the commission and its engineers and experts.

Speaking for myself, I found the precedents established by Texas, Michigan and Wisconsin of little value, either in deciding the methods to be pursued in making the appraisals or in estimating the probable cost of the appraisal. I ascertained that the state of Wisconsin had spent about $11 per mile of railway for making the appraisal and the railways themselves had spent an equal sum, making a total of about $22 per mile for the joint work done by the state and by the railways, for they both worked together in making the appraisals. When I started the appraisal of the railways of Washington I believed that the appraisal would cost far less than $11 per mile, and I am glad to say that the cost has actually been not more than $13 a mile, although I regret that it was even as much as that. I had no precedent to guide me in estimating the cost of going through the accounting records of the railways, and I underestimated the time and labor involved in that undertaking. Railway accounting records nearly 40 years old had to be discovered and analyzed. I say "discovered," for the railways themselves did not know the nature of these early records, even if they knew of their very existence, which in many cases they did not.

At this point it may be well to explain that these early records are far from being worthless, as many persons have assumed, for the subsequent improvements and betterments can be added to these original costs, and thus bring the total cash expenditures down to date. This total cash expenditure is a wonderful aid to the engineer in estimating the cost of reproduction. To illustrate by an example, take the actual cost of the item of "Engineering" on the Northern Pacific Railway. Up to June 30, 1906, it has amounted to $2,900,000 for the state of Washington, or about 5% of the total actual cost of construction and betterments. An investigation of this seemingly high percentage disclosed two big items, one being about $300,000 for the exploration surveys in the Cascade Mountains. At the time these surveys were made, no maps were in existence, and the railway engineers were compelled to explore the entire Cascade Range from the Canadian boundary south to the Columbia River. To-day, in reproducing the Northern Pacific Railway, no such elaborate exploration is necessary, and, if it were eliminated, the cost of engineering would be reduced to $2,600,000. In like manner certain other items of engineering would be reduced, so that the total cost of engineering should not exceed $2,500,000, which is the sum that I used in estimating the item of engineering when making my estimate of the cost of reproduction. It would take several hundred pages to explain my analysis of the original costs, and my use of the data thus obtained in guiding my judgment as to a proper allowance for the cost of reproduction of each item. I wish, however, to say had I not secured the original costs I am positive that my costs of reproduction would be nothing better than engineering guesses in so far as certain items are concerned. For example, the cost of grading, especially through rough and mountainous country cannot be accurately ascertained to-day by

any engineer not possessed of the original records showing the quantities, and classification of excavation, or of the actual costs of doing the grading work. It is true that in the entire absence of original records of any sort, an engineer can go into the field, and cross-section the existing "cuts" and "fills," and make an estimate of yardage of the different classes of excavation, but I should never do this except as the very last resort, and then with the determination of adding a very large percentage for contingencies.

I may state at this point that one of the most potent reasons for securing the original quantities and original costs is to eliminate the item of "contingencies" entirely. It sounds little enough to speak of 10% added for "contingencies," but it would have meant adding just $5,000,000 to my estimate of the Northern Pacific Railway alone.

Reverting briefly to the cost of appraising the railways of Washington, attention should be called to the lack of logic in estimating the cost of such appraisals in terms of the mile as the unit. The Wisconsin appraisals cost $22 a mile, but the Wisconsin railways have an appraised value of only $30,000 a mile; hence the Wisconsin appraisal cost 70 cts. per $1,000 appraised. The Washington appraisal cost $13 a mile, but the Washington railways have an appraised value of $60,000 per mile; hence the Washington appraisal cost 20 cts. per $1,000 appraised, as against 70 cts. in Wisconsin. There is not the slightest doubt that it costs more per mile to appraise a line worth $60,000 a mile than to appraise one costing $30,000 a mile, if the same methods of appraisal are used; for the $60,000 line contains many more structures and details per mile, and higher land values, involving more labor on the part of both accountants, engineers and right-of-way appraisers. If this is so, it will be asked why the Washington appraisal cost less per mile than the Wisconsin appraisal. An answer leads me into the subject of the methods used in making the Washington appraisal, for upon those methods depends the relative economy.

Methods of Appraisal.—Before entering upon the task of appraising the Washington railways I had secured all desired information as to the appraisals of the railways in Texas, Michigan and Wisconsin. I also saw the engineer of the Minnesota Railway and Warehouse Commission, who had been engaged for six months on the appraisal of the Minnesota railways. I found that the Wisconsin and Minnesota methods of appraisal were practically identical. Both states furnished printed blanks to the railways, and required the railways to make a detailed estimate of the cost of their own property. Upon securing such estimates, the states' engineers checked up the appraisal. This method is advocated largely on the ground that it avoids duplicating the expense of an appraisal, the assumption being that each railway itself will make its own appraisal in any event, whether asked to or not. Therefore, if the railway is required to make its own appraisal first, the state's engineer need not go through all the details, but can accept most of the matter after a more or less cursory inspection.

I was wholly dissatisfied with this method; for I felt that it would make it almost imperative for me to accept the appraisals made by the railways, practically at their own figures, or to undertake in the end what I could just as well undertake in the beginning, namely an independent investigation of my own. I need scarcely say that the results of the investigation have served to confirm my position on this point.

Neither the state of Minnesota nor Wisconsin had gone into the matter of the actual cost of the original railway property. This seemed to me a serious omission, not merely because of the Nebraska rate case decision, but because of the invaluable data that an investigation into actual costs would disclose.

In estimating the present or depreciated value of structures, rolling stock, etc., both Michigan and Wisconsin had sent experts into the field to estimate the percentage of present value of each unit. In this manner 40,000 freight cars were inspected in Michigan, and their "present value" estimated. To me this seemed to be not only a useless procedure, but very erroneous. Aside from the great expense of thus inspecting each car and structure, I was influenced by a belief in the far greater accuracy of applying what might be termed "mortality tables of structures." If the age of a man is known, his expectation of life can be estimated from mortality tables. Insurance companies do not have their doctors guess at the man's probable life. The doctor merely reports the man as not suffering from disease, and the insurance company having the man's age, applies its mortality tables. In like manner, it seemed to me, the "present value" of a car or locomotive could be accurately estimated if its present age were known. It is a well-established fact that a freight car has a useful life exceeding 20 or 25 yrs. If the average car has a life of 25 yrs., it loses 4% of its life every year. Hence, by multiplying its age in years by 4%, its lost life or depreciation is accurately ascertained; and by subtracting this depreciation from 100 the remainder will give its "present value," expressed as a percentage of its value new.

I believed that it would be far less expensive to ascertain the age of each car and each structure from the records of the companies, and to estimate the present value by the method just explained, than to inspect each structure in the field. This proved to be the case, and it effected a very substantial saving in the cost of appraisal, while, at the same time, it yielded more reliable results.

In some cases the records in the engineering offices of the railways did not show the ages of existing structures, but in such cases their accounting records showed the dates when structures were built, or when cars were purchased.

If practically all the structures shown in the accounting records are still in existence, and the money expended each year for each class of structure is known, it is a very simple matter to figure the average age of the money invested in such structures, which, after all, is what is needed in estimating present value. To illustrate.

suppose there are a number of station buildings in existence, whose age is not known. Suppose, however, that $10,500 was spent for such buildings in 1896, $20,000 in 1900, and $5,000 in 1902. Then, in 1906, the average age of the money invested in these buildings is ascertained thus:

$10,500	x	10 yrs.	equals	$105,000	one year
$20,000	x	6 yrs.	equals	$120,000	one year
$5,000	x	4 yrs.	equals	$20,000	one year
$35,500	x	7 yrs.	equals	$248,500	one year

This gives a total of $35,500 invested 7 yrs.; for $35,500 × 7 yrs. equals $248,500 one year.

The rule to be followed in all such cases is to multiply the money expended each year for structures of a given class by the age in years, add all these products together, and divide by the total cost of all the structures under consideration. The quotient is the average age of all the structures, or, more strictly speaking, the average age of the money invested in the structures. If some of the structures are no longer in existence, this method can still be applied. Take railway cross-ties, for example. Ascertain the total value of cross-ties in the track, then go back through the records of cost and tie renewals, by years, until the total cost of the renewals adds up to the total value of ties now in the track. Then compute the average age as above shown. If the price of ties has fluctuated, ascertain the actual price paid, and reduce all yearly expenditures of renewals to the present price.

It will be impossible, as well as undesirable, in a report of this character, for me to indicate all the methods pursued in the appraisal of railways, but some of the radical departures from precedent should be outlined, particularly where a result is secured in more thorough or in a more economic manner. Moreover, any chief engineer who may be in your employ in the future will be greatly handicapped without an outline of the methods pursued in this original appraisal.

In searching the records of the railways, I did not confine myself merely to their engineering and their accounting books, but often found missing links of information in the most incongruous places. The Oregon Railroad & Navigation Company, for example, had practically none of its "construction ledgers," and at first we despaired of being able to piece together a complete itemized summary of original cost. Finally we found an old tissue copy book, Book No. 51, at the Ash St. Dock in Portland, containing copies of the auditor's distribution sheets, showing costs of engineering, grading, etc., etc.

For several months our work was considerably retarded, not only by the reluctance of several of the railway companies to assist us in finding their records, but by the incompleteness of the records when found. Little by little, however, we were able to fill in the gaps, until there remained not 10% of the original unascertained.

For the guidance of any engineers whom you may employ in the future, I give a list of the most important records to be looked for in making an appraisal of this character.

1. Annual reports to stockholders.
2. Annual reports to Interstate Commerce Commission.
3. Annual report of chief engineers and superintendents to the president of the road.
4. Reports of minor officials.
5. Progress profiles.
6. Cross-section and quantity books.
7. Final estimates on contract work.
8. Tissue copy books of final estimates.
9. Rail and ballast charts.
10. Bridge books (engineering department).
11. Building books.
12. Work orders.
13. A. F. E.'s (authorization for expenditure).
14. Accounting records (a) Construction Ledgers, (b) General Ledgers and their accompanying journals, (c) Vouchers, Registers, (d) Vouchers, (e) Auditor's Distribution Sheets, and the like.
15. Equipment Registers.
16. Distribution Book, or Disbursement Accounts Books, containing directions for accountants to follow.
17. Confidential Reports.

In my judgment the first step to be taken in appraising a railway is to ascertain its physical and financial history. For this purpose the annual reports to stockholders are an invaluable source of information. By a perusal of these reports an historical map or chart can be prepared showing the limits of each "construction division" or branch of the railway, and the dates of beginning and completing the construction work on it. The present "operating divisions" often have the same names as certain "construction divisions" of the road, but wholly different limits. Hence the necessity of an historical map in order to avoid confusion in interpreting the accounting records of the road.

Having prepared a map, and a brief history of the road, the next step should be an investigation of the accounting department records. The tendency of a civil engineer is to go to the engineering records first, but this is a mistake, for the accounting records are usually kept in a much better shape, and contain fewer gaps. From the construction ledgers, an itemized account of the original cost of each construction division is secured, and having been secured, the next step is to check it by the records of the engineering department, where quantity books and tissue copy books of final estimates paid to contractors, and the like, are usually to be found. Frequently, however, it happens that a line has been purchased, and that only the engineering records were transferred at the time of the purchase. In which event it may be impossible to secure the

accounting records, except by going to the original owners of the property.

Having gone rapidly through all the accounting and engineering records to ascertain what gaps, if any, exist as to original construction data, the next step is to put engineers into the field to supply the missing links by actual inspection, measurement, etc. An attempt to estimate by field survey should be the last resort, not only on account of the greater cost of field work, but because of its greater inaccuracy, and finally—but not to be ignored—because, in case of a legal dispute as to the estimated cost, field surveys, and estimates made by different engineers are likely to differ widely. There is always so much that cannot be seen, like the foundation of bridges, the percentage of loose rocks in embankments, etc., that a field survey should be used only as a last resort. And, in our appraisal of the Washington railways, field surveys were made only for a very small percentage of the total mileage.

A field inspection of every mile of track should be made, preferably by an engineer riding on a handcar. This engineer should be provided with complete, up-to-date profiles, and small scale plans of the road, showing all structures and their dimensions, etc. I made the mistake of accepting the existing profiles and plans for use by the field inspectors. These records were so often incorrect, through not having been kept up to date, as to cause much unnecessary work subsequently in checking. Haste in sending out field inspectors is a mistake, as field inspection of this sort is the most inexpensive item of an appraisal, and can be quickly done even with a comparatively small force. One man on foot will inventory about 12 miles of ordinary track each day, or twice that amount on a handcar. Field inspection, therefore, should not be begun until corrected, up-to-date profiles and maps have been prepared, and until the investigation of the engineering records has been carried far enough to disclose the particular structures upon which the office records are incomplete. By doing this, the field inspection resolves itself into a checking off of structures with an occasional pause to measure some structure on which the office records are defective.

The appraisals heretofore made in other states have been based almost entirely upon field surveys and inspection, no attempt having been made to secure the necessary data from the engineering and accounting records of the railways. Why? The answer is found in the *purpose* of the appraisal. As previously stated, the *purpose* of the appraisals in Texas, Michigan and Wisconsin was not the same purpose as in Washington. Where the *purpose* is taxation, a railway naturally seeks a low valuation for its property, hence it prefers to refuse access to its own records, believing—and believing rightly—that what cannot be seen with the eyes will not be likely to appear in the appraisal. An appraisal by field examination solely is very apt to be below the true value of the property, hence the acceptability of such an appraisal by the railways where taxation is the *purpose* of the appraisal.

Several of the principal railway system in Washington at first resisted our efforts to secure the records in their offices, and stated that the records were so incomplete as to be valueless. In some instances I have no doubt that this was an honest opinion. I am inclined to believe, however, that their motive in resisting an examination of the records was, in some cases at least, to secure an appraisal which could be fought in the courts, and probably upset by documentary evidence to prove its unreliability in parts, if not in its entirety. Therefore, I hold to the belief that an investigation of both the accounting and engineering records of the railways would have been the best policy, even had it cost many times what it did cost. And, to show my reason for this belief, I will cite just one example. In testifying before your honorable body, Mr. Hogeland, chief engineer of the Great Northern Railway, has estimated the cost of earth excavation to be made up of three different items, as follows:

	Per cu. yd.
Average contract price up to 1,000 ft. haul	$0.230
Average overhaul	0.035
Transportation of men's tools, supplies	0.045
Total	$0.310

Had we not secured the actual records in the Great Northern offices, it might have been a difficult matter to convince the court that the last two items of the above estimate are ridiculously high. Having the records, it will not be so difficult. For example, the actual cost of the item of "average overhaul" was just one-seventh of Mr. Hogeland's estimate, or one-half cent per cubic yard, as shown in my statement of the actual cost of construction of the Great Northern Railway in the state of Washington. The item of transportation of men was similarly overestimated.

I will not enter into such details further, but, in justice to myself and you, I feel it my duty to explain *why a departure from precedent in railway appraisal was the best policy.* Such an illustration as the above will serve better than many generalities to show the character of the reasons for our exhaustive investigations into the original cost of the railways of this state. Were you, as a court, or were any other court, confronted by the conflicting testimony of expert engineers, it would be difficult to arrive at a just opinion as to proper quantities and prices, unless the actual data were available to guide you. The data are available and are now in your possession.

I have not touched upon the very important matter of the appraisal of the rolling stock, or equipment, further than to say that I did not make a field inspection of it. The office records were so complete that such an inspection was superfluous, and for the reason above given. In order to apportion to the state of Washington its share of the cost of the rolling stock, it was necessary to

appraise the entire equipment of every railway system entering the state. This, in itself, is no slight task. Several states should share the cost of appraising the equipment of the railways, so that the whole cost would not fall on one state, as in this instance.

If Washington, Idaho, Montana, the Dakotas and Minnesota could have acted in concert, the cost of railway appraisal would have been very much less, not only because of the distribution of the cost of appraising the equipment, but because of the facility with which an entire railway system can be appraised once an engineer becomes familiar with the accounting and engineering records of that railway system. For this reason, as well as for others, the railroad commissioners of certain groups of states should strive to act together.

The appraisal of right-of-way lands and station grounds, as far as present value goes, was delegated principally to three right-of-way experts, men who had been buying lands for railway purposes in Washington and were familiar with prices. Your honorable body adopted a method of arriving at land values which was entirely novel, and, to my mind, a vast improvement over any other method hitherto used in other states. The method consists in calling in real estate men in all the large cities, and securing testimony from those men as to land values. Your honorable body, sitting as a court, hears the testimony not only of the regularly employed right-of-way experts, but of expert real estate witnesses, which those right-of-way experts have consulted, and other real estate experts which the railways may bring in. Hitherto the practice has been to examine all real estate transfers within a certain distance of the railway property, and for a period of years prior to the appraisal, and to base the appraisal upon these transfers. Since property for railway purposes usually costs more than for other purposes, it is necessary to multiply the value ascertained from transfers of adjacent property by some factor, this factor being ascertained from expert testimony or otherwise. Unfortunately the records of the real estate transfers are not the best evidence of the value of the property transferred. Indeed the records are often made so as to *conceal* the real value of the property. For this reason alone the method devised by your honorable body is much to be preferred. Moreover, it is a less expensive method of appraising lands.

As to my methods of appraisal I need say little more. My testimony before your honorable body is complete on those matters, but, being of great length, I have thought it wise to summarize certain features in this report, giving also a few suggestions, which may assist any engineer who may be in the employ of the Washington Railroad Commission in future.

It is needless to tell you, but for the sake of public record I desire to say that on all the smaller railways in Washington I was given most courteous treatment, and had ready access to all records. On the three large systems, namely the Great Northern, the

Northern Pacific, and the Oregon Railway & Navigation Company, I met with much resistance at first, and lost several months of time in consequence. Denial as to the existence of certain important records was repeatedly made—records that I subsequently found. Possibly these denials were made in good faith, but, since free access to all records was not given me by the Great Northern and the Northern Pacific for a long time, and then only after I pieced together enough information to prove the existence of the desired records, my work was greatly retarded. I think that these railways came ultimately to see that it was an error not to put all records at my disposal, and all I regret is that they were not prompt in reaching that conclusion. I regret it not only because of the increased cost of the appraisal, but because I had business duties in New York that made my return imperative at as early a date as possible.

In conclusion I wish to express my hearty appreciation of the loyalty and zeal with which my assistants worked. Those in the most important positions worked not only by day but by night. I know of no one who seemed swayed by the fear of "working himself out of a job." My two principal assistants, Mr. Francis W. Collins and Mr. H. L. Gray, deserve special recognition in this report, for upon them fell the brunt of the task. Mr. Collins was located in St. Paul, at the offices of the Great Northern and the Northern Pacific railways, with a corps of men under his direction. Mr. Gray was located in Portland, in the offices of the Oregon Railway & Navigation Company, with a similar corps.

To your honorable body I wish to express my sincere thanks for the many valuable suggestions that came from you as to the conduct of my appraisal. I wish it were possible for me to convey to the people of Washington my unbiased opinion of your honorable body. As a non-resident my opinion is unbiased. I believe you have shown great wisdom in not allowing yourselves to be hurried into action, for the sake of being able to point to "results." No ordinary citizen can realize the magnitude and the intricacy of the problem before you. It can become appalling only to one who has come face to face with it, and has delved into its details. So far as I know, you are the first state railway commission in America that has not allowed itself to be drawn into action on rate making before securing the fundamental facts that should govern such action. One of those fundamental facts is the physical value of the railways in the state. A physical valuation is absolutely essential, if for no other purpose than to determine a reasonable amount to set aside annually from earnings to cover the depreciation from natural agencies and from wear and tear. Tell me the physical value of a given structure, and I can estimate its depreciation in dollars closely. Conceal that value, and I am utterly in the dark. It has become the fashion to "poo-hoo" the necessity of a physical valuation of railways by commissions having rate-making powers. Even had the Supreme Court not ruled as to the necessity of a physical valuation, the necessity would exist, if for

no other reason than to solve the important problem of annual depreciation.

Original Cost and Cost of Production of the Great Northern Railway (768 Miles) in the State of Washington.*—This article will contain data that have not hitherto appeared in print. In fact the detailed, actual cost of construction of no large mileage of American railway has ever before been published, so far as we know.

Two years ago the Railroad Commission of Washington conducted a hearing at which the data collected by the Chief Engineer of the Commission, Mr. Halbert P. Gillette, were put in evidence, together with testimony as to the methods used in securing the data. Mr. Gillette subsequently condensed his testimony, as to sources of information and general methods used, into a brief report which formed part of the annual report of the Commission, and was reprinted in *Engineering-Contracting*, April 7, 1909. It was obviously impracticable to print in the report the mass of typewritten statistics forming Mr. Gillette's exhibits, so the Commission wisely printed only the results of its "findings" after listening to testimony submitted by the railways.

The gathering of the data kept a corps of some 20 engineers and land experts busy for a year in the office and in the field. Many of the data are of a character meriting publicity. We have, therefore, selected the most important parts from Mr. Gillette's exhibits and testimony, and will publish them. The first installment is in the present article and relates to the Great Northern Railway.

The major portion of this road in Washington was built, as a single-track line, in the years 1891 to 1894. It was built by contract at reasonable prices, and, in spite of the fact, that a rugged range of mountains was crossed, the original cost of 488 miles of line was only $21,673,780, as shown by the accounting records, or $44,400 per mile, including right of way and all costs except rolling stock. As will be noted below, the item of engineering was 3% of the total cost.

While the accounting records of the Great Northern did not comply precisely with the requirements of the Interstate Commerce Commission, still the departures were few—and for the best—so the items, as given below, are practically self-explanatory.

The section of line whose costs follow embraces the line as originally built (not including subsequent additions and improvements) from the Idaho-Washington boundary to Everett, from Seattle to Belfast, and from Anacortes to Rockport, a total distance of 487.6 miles. The original cost of this mileage was as shown in Table VI.

**Engineering-Contracting*, Dec. 8, 1909.

TABLE VI.—ORIGINAL COST OF 488 MILES OF GREAT NORTHERN RAILWAY LINE IN WASHINGTON.

	Item.	Total.	Per Mile of Line or Roadbed.
1.	Engineering	$ 643,513.39	$ 1,319
2.	Right of way	1,978,874.53	4,056
3.	Real estate	112,064.64	230
4.	Clearing and grubbing	536,157.05	1,098
5.	Grading	5,534,879.90	11,343
6.	Tunnels	2,744,686.14	5,624
7.	Masonry	459,436.06	942
8.	Cribbing and bulkheading	348,287.42	714
9.	Bridges and culverts	2,106,876.45	4,318
10.	Cattle guards, road crossings and signs	114,274.79	234
11.	Ties	584,464.37	1,198
12.	Rails	2,894,548.33	5,932
13.	Rail fastenings	377,508.94	774
14.	Frogs, switches, etc.	82,423.78	169
15.	Tracklaying and surfacing	259,005.76	532
16.	Ballasting	530,483.41	1,088
17.	Surfacing, filling and lining track	30,256.99	61
18.	Transportation dept. buildings	300,141.08	615
19.	Road dept. bldgs.	43,294.71	88
20.	Roundhouses and shops	159,715.46	328
21.	Fuel and water stations	125,811.22	258
22.	Docks, wharves and inclines	21,476.57	44
23.	Columbia River incline	59,485.91	122
24.	Other buildings and structures	12,136.70	25
25.	Fences	11,219.03	22
26.	Telegraph	22,921.68	47
27.	Shop tools and machinery	47,233.90	96
28.	Protection against snow and ice	77,187.95	158
29.	Locomotive and car service	42,287.03	86
30.	General expense	52,854.13	108
31.	Transportation men and materials.	45,065.31	92
32.	Insurance	549.90	1
33.	Operating expense	251,323.52	514
34.	Interest on advances	244,442.95	501
35.	Bond expenses	36,065.80	74
36.	Bond interest during constr.	766,139.99	1,569
37.	Wagon roads	15,778.78	32
	Total	$21,672,873.57	$44,412

There were 488 miles of railway line, or roadbed, and the side tracks, etc., amounted to about 8% additional; so that the costs per "mile of line" in Table VI should be divided by 1.08 to arrive at the costs per "mile of track."

Three items in Table VI bring out very clearly the rough character of the country, namely. Items 5, 6 and 9. The Cascade Tunnel comprised almost the whole of Item 6, the actual cost of that tunnel being $2,524,212, including masonry lining.

The original grading quantities and classification were as given in Table VII.

The part of the Idaho Division that lies within the state of Washington was 48.77 miles long. The Washington Division extended to the foot of the "switchback" line, which was called the "Overhead Line," over the Cascade Mountains. The "switchback" was subsequently abandoned in part when the tunnel was com-

TABLE VII.—GRADING QUANTITIES.

Division.	Idaho.	Wash'ton.	Overhead.	Pacific.	S. & M.	S. & M.	Total.
Miles of line, or roadbed	48.77	227.08	11.70	74.46	75.31	54.42	491.76
Earth excav. within 300 ft. (cu. yds.)	227,966	515,673	3,346	248,891	431,329	379,408	1,806,613
Earth evcav. within 1,000 ft. (cu. yds.)	324,149	473,675	....	149,246	256,060	76,008	1,279,138
Cemented gravel (cu. yds.)	153,002	1,242,834	112,607	635,531	430,883	243,809	2,818,666
Loose rock (cu. yds.)	66,242	360,135	49,558	256,191	89	7,006	739,221
Solid rock (cu. yds.)	193,252	931,899	77,146	824,698	262	43,753	2,071,010
Embankment (cu. yds.)	429,193	1,864,107	2,879	693,651	781,226	....	3,771,056
Unclassified (cu. yds.)	....	....	....	....	....	299,866	299,866
Total	1,393,804	5,388,323	245,536	2,808,208	1,899,849	1,049,850	12,785,570
Overhaul, cu. yds., 100 ft.	4,446,428	353,253	....	78,007	714,706	193,079	5,785,473
Clearing, acres	509	756	167	952	881	332	3,547
Grubbing, stations	1,038	1,213	584	2,370	1,770	909	7,884
Cu. yds. excav. and embank., per mile.	28,600	23,700	20,800	37,700	25,200	19,300	26,000

pleted. The Seattle and Montana (S. & M.) extended along Puget Sound from Seattle to Belfast. The Seattle and Northern (S. & N.) extended from Anacortes to Sauk.

The contract prices were quite uniform, and were about as follows per cubic yard:

Earth excav. hauled less than 300 ft.	$0.17
Earth excav. hauled 300 to 1,000 ft.	0.21
Cemented gravel hauled less than 1,000 ft.	0.38
Loose rock	0.42
Solid rock	1.05
Embankment from borrow pits	0.17
Overhaul, for each 100 ft. beyond the free haul of 1,000 ft.	0.01

Grading was paid for but once.

It is interesting to note that the average grading was 26,000 cu. yds. per mile, classified as follows:

	Per cent.
Earth excav. within 300 ft.	14.4
Earth excav. within 1,000 ft.	10.3
Cemented gravel	22.6
Loose rock	5.9
Solid rock	16.6
Embankment from borrow pits	30.2
Total	100.0

There was less than 50 ft. of overhaul on the average cubic yard of excavation, or less than ½ ct. per cu. yd for overhaul.

The average cost of grading, including overhaul, was about 40 cts. per cu. yd. of all excavation.

The price of clearing ranged from $28 an acre in the Idaho Division to $139 in the Pacific Division. Grubbing ranged from $14 a station in the Idaho Division to $25 a station in the Pacific Division.

The price of tracklaying was about $230 per mile and the price of surfacing was about $200 per mile.

Items 29, 30 and 31 are especially interesting in view of the absurd testimony that has often been given as to these items.

Item 33, Operating Expense, is the cost of operating trains over the line prior to its being turned over to the operating department.

Items 34, 35 and 36, total $2,144 per mile, or about 4.8% of the total cost, which shows that an allowance of 5% for interest during construction is ample, although it has been frequently claimed that double this amount should be allowed.

A short line was built in northwestern Washington, from Bellingham northward and southward, called the Fairhaven Southern Ry. Part of it was subsequently abandoned. The remaining part was 32.3 miles long. Its cost was determined from the accounting records of its original builders, to which was added the costs shown in the Great Northern Ry. after it had passed into the latter's hands. This total cost for the 32.3 miles of line was as given in Table VIII.

TABLE VIII.—COST OF FAIRHAVEN SOUTHERN RY. (32.3 MILES OF LINE OR ROADBED).

	Item.	Per mile of line.
1.	Engineering	$ 749
2.	Right of way	2,230
3.	Real estate	84
4.	Clearing and grubbing (very heavy)	1,083
5.	Grading	4,013
6.	Masonry	436
7.	Cribbing and bulkheading	248
8.	Bridges and culverts	4,196
9.	Cattle guards and signs	7
10.	Ties	751
11.	Rails	4,303
12.	Rail fastenings	498
13.	Frogs, switches, etc.	16
14.	Tracklaying and surfacing	396
15.	Ballasting	653
16.	Transportation department buildings	545
17.	Road department buildings	149
18.	Roundhouses and shops	158
19.	Fuel and water stations	273
20.	Other buildings and structures	257
21.	Fences	121
22.	Telegraph	211
23.	Shop tools and machinery	239
24.	Locomotive and car service	189
25.	General expense	748
26.	Insurance	12
	Grand total	$22,565

The following were the grading quantities per mile and contract prices on the Fairhaven Southern:

9,200 cu. yds. earth, at $0.21.
2,000 cu. yds. cement gravel, at $0.35.
400 cu. yds. loose rock, at $0.40.
1,300 cu. yds. solid rock, at $1.02.

12,900 cu. yds. total per mile.
4,800 cu. yds. overhauled 100 ft., at $0.01.

This is fairly typical of the yardage per mile of branch line built through "easy country."

Item 14, tracklaying, does not include train service, which is given in Item 24 for the entire construction of the road and is not prorated to the other items.

No interest was charged on the books.

The Spokane Falls and Northern Ry. was also built in the early 90's, by an independent company, whose cost records could not be secured. A field survey was accordingly made, and its cost was estimated, using prices that were common at the time of the construction of the line. This line is 130.5 miles long, and its original construction cost was estimated to have been as given in Table IX.

TABLE IX.—ESTIMATED ORIGINAL COST OF THE SPOKANE FALLS AND NORTHERN RY. (130.5 MILES OF LINE OR ROADBED).

	Item.	Per mile of line.
1.	Engineering	$ 524
2.	Grading	5,132
3.	Bridges and culverts	1,164
4.	Cattle guards and signs	24
5.	Ties	1,612
6.	Rails	4,031
7.	Rail fastenings	791
8.	Frogs, switches, etc.	70
9.	Tracklaying and surfacing ($700 per mile of track)	835
10.	Ballasting	600
11.	Transportation department buildings	396
12.	Road department buildings	107
13.	Fuel and water stations	147
14.	Other buildings and structures	14
15.	Fences	63
16.	General expense	150
17.	Bond interest during contruction	785
	Grand total	$16,445

In addition to the 130.5 miles of line there were 20.79 miles of sidetracks, etc.

It will be noted that no land is included in this estimate, but $1,000 per mile of line was the estimated value of the land in 1906. It was certainly much less originally. This line was probably built for $17,000 per mile, including all land.

The Great Northern Ry. had just completed in 1906 a stretch of branch line in northern Washington, known as the Washington & Great Northern Ry. The completed portion was 83.9 miles long, through a mountainous country. The grading yardage per mile of line, and contract prices, were as follows:

9,200 cu. yds. earth excav. under 300 ft., at $0.18
5,600 cu. yds. earth excav. under 1,000 ft., at $0.22
9,000 cu. yds. cement gravel, under 1,000 ft., at $0.35
1,800 cu. yds. loose rock under 1,000 ft., at $0.40
6,900 cu. yds. solid rock under 1,000 ft., at $0.93

32,500 cu. yds. total per mile
19,000 cu. yds. overhauled 100 ft., at $0.01

The actual cost of this line was as given in Table X.

TABLE X.—ORIGINAL COST OF THE WASHINGTON AND GREAT NORTHERN RY. (83.9 MILES OF LINE OR ROADBED).

	Item.	Per mile of line.
1.	Engineering	$ 1,489
2.	Right of way	1,064
3.	Real estate	3
4.	Clearing and grubbing	656
5.	Grading	14,558
6.	Tunnels	75
7.	Masonry	928
8.	Bridges and culverts	3,623
9.	Cattle guards, road crossings and signs	17
10.	Ties	1,035
11.	Rails	5,261
12.	Rail fastenings	700
13.	Frogs, switches, etc.	161
14.	Tracklaying and surfacing	866
15.	Ballasting	1,024
16.	Surfacing, filling and lining track	34
17.	Transportation department buildings	139
18.	Road department buildings	123
19.	Roundhouses and shops	22
20.	Fuel and water stations	389
21.	Other buildings and structures	5
22.	Fences	50
23.	Telegraph	127
24.	Locomotive and car service	575
25.	General expense	25
26.	Transportation of men and materials	2,378
27.	Insurance	2
28.	Operating expense	19
29.	Interest on advances	1,099
30.	Taxes	56
31.	Wagon roads	17
	Grand total	$36,519

In addition to the 83.9 miles of line there were 7.89 miles of sidetracks, etc., whose cost is included above.

It will be noted that Item 1, Engineering, cost about 4% of the total; and that Item 29, Interest During Construction, was about 3% of the total.

In addition to the foregoing lines belonging to the Great Northern there was a short line, The Columbia & Red Mountain, 7.5 miles long, whose original cost could not be ascertained, but was estimated to have been $258,327, or $34,450 per mile.

The preceding costs total as follows:

Main line (487.6 miles)	$21,673,780
Fairhaven & Southern (32.3 miles)	728,976
Washington & G. N. (83.9 miles)	3,054,042
Spokane Falls & N. (130.5 miles)	2,145,682
Columbia & Red Mt. (7.5 miles)	258,327
Total original cost	$27,860,807

If we allow $140,000 for the probable cost of the right of way of the S. F. & N., we have $28,000,000, in round numbers, for 742 miles

of line, or $37,730 per mile, not including rolling stock. This is very close to the actual original cost.

We come now to the additions and improvements made since the original lines were built. They total as follows:

Fairhaven cut-off line (18.4 miles)	$ 962,102
New side tracks	747,209
Right of way	745,370
Real estate	2,519,513
Grading (mostly bank widening)	1,142,369
Tunnels	1,250,145
Masonry	729,409
Cribbing and bulkheading	19,457
Bridges and culverts	465,520
Rails	52,207
Transportation department buildings	503,968
Road department buildings	50,541
Roundhouses and shops	90,333
Fuel and water stations	49,334
Grain elevators, coal bunkers, etc.	104,933
Docks and wharves	546,926
Other buildings and structures	177,480
Fences	39,523
Telegraph	6,884
Shop tools and machinery	96,136
Protection against snow and ice	111,501
Total additions and improvements	$10,410,859

This brings the cost up to June 30, 1906.

Unfortunately the account of New Sidetracks does not distribute the cost between the various items, as it should; consequently Mr. Gillette adopted the following distribution:

	Per cent.
Grading	25
Ties	10
Rails	40
Rail fastenings	10
Frogs and switches	10
Laying and surfacing	5
Total	100

In this manner the total itemized cost (original plus additions and improvements) was arrived at very closely, as shown in Table XI.

Table XI includes no allowance for the right of way of the S. F. & N. and of the Columbia & Red Mountain; but, as the present value of that right of way is only $139,678, it will be seen that the grand total cost was about $38,400,000.

In using Table XI the reader should be cautioned that the Additions and Improvements were not recorded in the accounting department exactly under the same headings as were the original construction costs. It was an error not to have done so, but it is the common practice of railway companies to make this mistake. Engineering, for example, is not recorded as a separate item in the Additions and Improvements (except on the "Fairhaven Cut-Off

Line," where it was 3% of the total); hence one cannot estimate the total cost of engineering on any part of the Great Northern work other than the *original construction*.

The same holds true of Locomotive and Car Service, Transportation of Man and Materials, and Interest during the time that work is in progress.

TABLE XI.—ORIGINAL COST OF GREAT NORTHERN RY., PLUS ADDITIONS AND IMPROVEMENTS UP TO JUNE 30, 1906 (767.75 MILES OF RAILWAY LINE AND 187.06 MILES OF SIDE TRACK AND OTHER TRACK).

	Item.	Total.	Per mile of line.
1.	Engineering	$ 897,523.10	$ 1,169*
2.	Right of way	2,885,290.66	3,759
3.	Real estate	2,634,533.12	3,432
4.	Clearing and grubbing	657,585.67	856
5.	Grading	9,561,212.68	12,454
6.	Tunnels	4,166,137.81	5,426
7.	Masonry	1,280,582.94	1,668
8.	Cribbing and bulkheading	375,779.13	489
9.	Bridges and culverts	3,275,652.60	4,266
10.	Cattle guards, road crossings and signs	119,026.15	155
11.	Ties	1,004,558.13	1,309
12.	Rails	4,425,000.32	5,763
13.	Rail fastenings	642,684.77	837
14.	Frogs, switches, etc.	186,760.15	243
15.	Tracklaying and surfacing	505,533.96	658
16.	Ballasting	760,517.22	990
17.	Surfacing, filling and lining track	34,095.90	44
18.	Transportation department buildings	885,130.96	1,153
19.	Road department buildings	122,739.99	160
20.	Roundhouses and shops	256,933.72	334
21.	Fuel and water stations	235,045.35	306
22.	Grain elevators, coal bunkers and stock yards	104,932.89	136
23.	Docks, wharves and inclines	627,888.57	817
24.	Other buildings and structures	200,984.65	261
25.	Fences	66,975.87	87
26.	Telegraph	47,185.27	61
27.	Shop tools and machinery	151,066.94	196
28.	Protection against snow and ice	188,688.99	245
29.	Locomotive and car service	96,536.47	126*
30.	General expense	101,109.98	132*
31.	Transportation men and materials	248,860.20	318*
32.	Insurance	1,117.43	1*
33.	Operating expense	252,948.48	329†
34.	Interest on advances	336,342.11	437*
35.	Bond expenses	36,065.80	47*
36.	Bond interest during construction	880,835.66	1,146*
37.	Taxes	4,696.89	6
38.	Wagon roads	17,198.97	22
	Total	$38,270,760.50	$49,848
39.	Equipment (rolling stock)	3,973,586.18	5,176
	Grand total	$42,244,346.68	$55,024

*These items relate only to original construction, and not to any of the work done under additions and improvements.

†Operating expense covers the cost of operating passenger and freight trains during construction (before the road was turned over to the operating department). This expense should really not be regarded as part of the cost of construction.

Since there were 0.244 miles of sidetrack and other tracks per mile of line, the costs in the last column of Table XI must be divided by 1.244 to arrive at the cost per mile of track. Multiplying by 0.8 will give almost the same result as dividing by 1.244.

Item 15 does not include all the surfacing, as will be seen by noting Item 17; but Item 15 includes locomotive and car service. The locomotive and car service of Item 29 relates to other work.

From the records of quantities in the engineering department of the Great Northern, supplemented by data in the accounting department, and by field surveys where necessary, Mr. Gillette prepared the estimated cost of reproducing (new) the Great Northern lines in the state of Washington, as detailed in Table XII. Item 2 (lands) in Table XII is based upon the final "findings" of the Washington Railroad Commission.

TABLE XII—ESTIMATE OF THE COST OF REPRODUCING THE GREAT NORTHERN RY. IN WASHINGTON, UP TO JUNE 30, 1906.

(767.75 MILES OF LINE AND 187.06 MILES OF SIDE TRACKS AND YARD TRACKS.)

1.	Engineering, 3½% of items 3 to 26 inclusive....	$ 1,077,601.47
2.	Right of way, etc.	
	Terminal land, Seattle........................	$10,937,543.69
	Terminal land, Spokane........................	1,562,228.33
	Terminal land, Everett........................	1,077,750.00
	Terminal land, Bellingham....................	552,610.00
	Right of way, and other station grounds......	2,975,560.02
	Total right of way, etc......................	$17,105,692.04
3.	Clearing and Grubbing.	
	Clearing, 4,968 acres at $100.00...............$	496,800.00
	Grubbing, 9,521 stations at $20.00............	190,420.00
	Cutting dangerous trees, 6,596 at $2.00........	13,192.00
	Total clearing and grubbing................$	700,412.00
4.	Grading.	
	Earth excavation (300 ft. haul), 2,802,453 cu. yds. at $0.20...............................$	560,490.60
	Earth excavation (1,000 ft. haul), 3,911,918 cu. yds. at $0.25..............................	977,979.50
	Cement gravel, 3,998,152 cu. yds. at $0.40......	1,599,260.80
	Loose rock, 1,186,985 cu. yds. at $0.50.........	593,492.50
	Solid rock, 3,246,964 cu. yds. at $1.10.........	3,571,660.40
	Unclassified excavation, 299,866 cu. yds. at $0.50	149,933.00
	Embankment, 3,771,056 cu. yds. at $0.20......	754,211.20
	Overhaul, cu. yds. hauled 100 ft., 8,361,186, at $0.01..................................	83,611.86
	Widening roadbed (acctg. records)...........	1,142,368.85
	Grading new side tracks (acctg. records)......	186,802.19
	Total grading (except trestles filled, item 8).$	9,619,810.90

5. **Tunnels.**

Cascade tunnel (masonry lined), 13,813 lin. ft. at $180.00	$ 2,486,340.00
Everett tunnel (in earth, timber lined), 2,259 lin. ft. at $60.00	135,540.00
Seattle tunnel (double track, in earth, masonry lined, ⅔ owned by G. N.), 5,141 lin. ft. at ⅔ of $360.00	1,233,840.00
Other tunnels, 5,316 lin. ft. at $75.00	398,700.00
W. & G. N. tunnel, 113 lin. ft. at $60.00	6,780.00
Total tunnels	$ 4,261,200.00

6. **Masonry.**

Riprap, slope wall and retaining wall (as per acctg. records, after deducting bridge and culvert masonry)	$ 865,718.94

7. Cribbing and Bulkheading.

As per accounting records	$ 375,779.13

8. Bridges and Culverts.

Trestles (av. 18 ft. high, 30,390,311 ft. B. M. at $30.00, and 1,234,583 lin. ft. piles at $0.25), 128,400 lin. ft. at $10.00	$ 1,284,000.00
Trestles filled, 2,048,038 cu. yds. at $0.20	409,607.60
Howe Truss and Combination Bridges (8,046 ft.).	
Spans under 60 ft., 966 lin. ft. at $30.00	28,980.00
Spans 60 to 100 ft., 825 lin. ft. at $35.00	28,875.00
Spans 100 to 150 ft., 3,909 lin. ft. at $45.00	175,905.00
Spans over 150 ft., 2,346 lin. ft. at $60.00	140,760.00
Steel Bridges (11,722 lin. ft.).	
Steel in place, 24,004,260 lbs. at $0.0475	$ 1,140,202.35
Foundation masonry, 30,267 cu. yds. at $12.00	363,204.00
Log Culverts (31,606 lin. ft. culvert).	
Logs in place, 538,741 lin. ft. at $0.16	86,198.56
Timber Culverts (12,922 lin. ft. culvert).	
Timber, 2,180,232 ft. B. M., at $26.00	56,686.03
Box Drains (3,709 lin. ft. drains).	
Timber, 62,080 ft. B. M., at $26.00	1,614.08
Concrete Culverts (2,377 lin. ft. culverts).	
Concrete, 4,740 cu. yds., at $9.00	51,660.00
Stone Box Culverts (3,206 lin. ft. culverts).	
Masonry, 4,074 cu. yds., at $5.00	20,370.00
Vitrified Pipe Culverts (11,870 lin. ft. culverts).	
12-in. pipe, 694 lin. ft., at $0.50	347.00
18-in. pipe, 2,848 lin. ft., at $1.30	3,702.40
24-in. pipe, 4,058 lin. ft., at $2.60	10,550.80
27-in. pipe, 3,583 lin. ft., at $3.00	10,749.00
30-in. pipe, 687 lin. ft., at $3.50	2,404.50
Cast Iron Pipe Culverts (6,159 lin. ft. culverts).	
8-in. pipe, 48 lin. ft., at $1.50	72.00
12-in. pipe, 606 lin. ft., at $3.00	1,818.00
18-in. pipe, 852 lin. ft., at $4.00	3,408.00
24-in. pipe, 3,119 lin. ft., at $6.00	18,714.00
30-in. pipe, 1,324 lin. ft., at $7.00	9,268.00
36-in. pipe, 210 lin. ft., at $9.00	1,890.00
Total bridges and culverts	$ 3,850,986.32

9. **Ties.**

(954.8 miles, at 3,000), 2,864,400 ties, at $0.50	$ 1,432,200.00

10. **Rails.**

(954.8 miles), 98,237 tons, at $40.00	$ 3,929,480.00

11.	**Track Fastenings.**	
	Spikes, 6,111,960 lbs., at $0.028 ....$	171,134.88
	Angle bars, 16,549,280 lbs., at $0.025	413,732.00
	Bolts, 1,692,540 lbs., at $0.032	54,161.28
	Rail braces, 382,500, at $0.10	38,250.00
	Tie plates (25% of line), 1,125,000, at $0.08	90,000.00
	Total track fastenings ....$	767,278.16
12.	**Frogs and Switches.**	
	Turnouts (frogs), 1,033, at $80.00 ....$	82,640.00
13.	**Ballast.**	
	Main line, 767.7 miles, at $1,000.00 ....$	767,700.00
	Side track, 187.1 miles, at $600.00	112,260.00
	Total ballast ....$	879,960.00
14.	**Tracklaying and Surfacing.**	
	Main line and side track, 954.8 mi., at $700.00..$	668,360.00
15.	**Fencing Right of Way.**	
	As per accounting records plus 20% ....$	80,371.04
16.	**Crossings, Cattle Guards and Signs.**	
	Signs, 3,020, at $2.00 ....$	6,040.00
	Road crossings (grade), 1,044, at $6.00	6,264.00
	Cattle guards, 295, at $20.00	5,900.00
	Tell tales, 18, at $25.00	450.00
	Steel highway bridges, 1,743 lin. ft., at $80.00..	139,440.00
	Wood highway bridges, 1,384 lin. ft., at $20.00..	27,680.00
	Total crossings, etc. ....$	185,774.00
17.	**Telegraph Lines.**	
	As per accounting records plus 20% ....$	56,622.00
18.	**Transportation Department Buildings.**	
	Passenger depots, frame, 95,573 sq. ft., at $1.25.$	119,466.25
	Passenger depots, brick, at Bellingham	18,000.00
	Passenger depot, brick, at Spokane	130,000.00
	Passenger depot, brick and stone, at Seattle (½ interest)	280,000.00
	Freight depot, brick, Spokane, 30,000 sq. ft., at $1.00	30,000.00
	Freight depot, brick, Everett, 9,350 sq. ft., at $1.00	9,350.00
	Freight depot, brick, Seattle, 16,245 sq. ft., at $1.00	16,245.00
	Freight depot, brick, Seattle (stores), 27,440 sq. ft., at $3.50	96,040.00
	Freight depot, brick, Seattle, 50,000 sq. ft., at $1.50	75,000.00
	Freight depot, frame, Seattle, 64,000 sq. ft., at $1.00	64,000.00
	Freight depot, frame, Seattle, 56,000 sq. ft., at $1.00	56,000.00
	Freight depot, frame, elsewhere, 21,822 sq. ft., at $1.00	21,822.00
	Warehouses, 18,648 sq. ft., at $1.00	18,648.00
	Stock yards, 277,662 sq. ft., at $0.04	11,106.48
	Track scales, 9, at $2,000.00	18,000.00
	Platforms, wood (other than depots), 38,422 sq. ft., at $0.10	3,842.20
	Platforms, cinder, 25,575 sq. ft., at $0.06	1,534.50
	Platforms, brick, 600 sq. ft., at $0.25	150.00
	Water closets, 3,638 sq. ft., at $1.00	3,638.00
	Station furniture (other than Seattle)	10,692.08
	Total transportation department buildings..$	983,534.51

19.	**Road Department Buildings.**	
	Section houses (white men), 56,538 sq. ft., at $1.25 ....$	70,672.50
	Section houses (Japanese), 22,826 sq. ft., at $0.80	18,260.80
	Tool houses, 14,050 sq. ft., at $0.50...........	7,025.00
	Total road department buildings...........$	95,958.30
20.	**Round Houses and Shops.**	
	Round houses, brick, 55 stalls, at $1,500.00....$	82,500.00
	Round houses, frame, 19 stalls, at $900.00....	17,100.00
	Cinder pits, 290 lin. ft., at $50.00.............	14,500.00
	Turntables, 9, at $3,000.00....................	27,000.00
	Machine and repair shops, brick, 117,315 sq. ft., at $1.25..............................	146,643.75
	Machine and repair shops, frame, 8,123 sq. ft., at $0.50	4,061.50
	Transfer tables, 2, at $1,500.00...............	3,000.00
	Repair sheds, 24,000 sq. ft., at $0.25...........	6,000.00
	Total round houses and shops..............$	300,805.25
21.	**Fuel and Water Stations.**	
	Water stations, 51, at $2,700.00..............$	137,700.00
	Coal chutes (5), 67 pockets, at $1,500.00......	100,500.00
	Total fuel and water stations..............$	238,200.00
22.	**Shop Tools and Machinery.**	
	As per accounting records plus 20%..........$	181,280.40
23.	**Grain Elevators.**	
	Sack house, Seattle, 50,400 sq. ft., at $0.50....$	25,200.00
	Elevator, Seattle	100,000.00
	Total grain elevators......................$	125,200.00
24.	**Docks and Wharves.**	
	Docks, Seattle ....$	626,368.60
	Wharves elsewhere, 30,000 sq. ft., at $0.75....	22,500.00
	Total docks and wharves..................$	648,868.60
25.	**Other Buildings and Structures.**	
	As per accounting records plus 20% (106,905 sq. ft. of miscellaneous buildings, etc.)......$	241,181.58
26.	**Snow Protection.**	
	As per accounting records plus 15%, (consisting mainly of 4,558 lin. ft. snow sheds)......$	216,992.35
27.	**Legal and General Expense.**	
	1% of items 3 to 26, inclusive...............$	307,866.13
28.	**Interest During Construction.**	
	5% of items 1 to 27 (except 2), inclusive....$	1,608,705.06
29.	**Stores on Hand.**	
	Necessary for maintenance and operation.....$	360,904.26
	Total of items 1 to 29, inclusive...........$	51,249,402.44
30.	**Equipment.**	
	Locomotives ....$	1,334,740.70
	Passenger cars	715,395.92
	Freight cars	2,320,036.29
	Work and miscellaneous..................	199,451.19
	Total equipment ....$	4,569,624.10
	Grand total of items 1 to 30...............$	55,819,026.54

Regarding Item 2 of Table XII, it should be said that the Railroad Commission did not include any land not needed in the immediate future for railway purposes. In the city of Seattle there was land, owned by the Great Northern, of the estimated value of $9,097,490, which is not included in Item 2. In Spokane there was similar land of the value of $221,750, and other leased lands (bringing $16,000 yearly income), whose value was not determined.

The chief engineer of the Great Northern presented an estimate of the cost of reproduction far in excess of that of Mr. Gillette above given. The Railroad Commission finally determined that $58,671,559 would be a fair cost of reproducing (new) the Great Northern lines in Washington, and that $53,887,080 would be a fair "present value," or second-hand value, of all this property, including equipment.

The accounting and engineering records of the Great Northern had been so kept that the yardage of earth in widening roadbed (subsequent to original construction) and in building new sidetracks, could not be ascertained without an amount of labor that did not seem to be warranted.

Referring to the last two entries in Item 4 of Table XII, it will be seen that they total $1,329,170, or about 14% of the total of Item 4. At an assumed cost of 20 cts. per cu. yd. for this bank widening, etc., there were about 664,600 cu. yds., which is equivalent to 865 cu. yds. per mile of line. Dividing the items of yardage in Item 4 by 768, the miles of line, we have the following:

	Cu. yds. per mile of line.
Earth excav. (300 ft. or less haul)	3,640
Earth excav. (300 to 1,000 ft. haul)	5,090
Cement gravel	5,200
Loose rock	1,540
Solid rock	4,230
Unclassified excavation	390
Embankment from borrow	4,910
Total	25,000
Widening roadbed (earth)	870
Total	25,870
Filling trestles (see Item 8, Table IV)	270
Grand total	26,140

In Item 8 it will be seen that the trestles averaged 18 ft. high. This was ascertained by dividing the total sum of the profile areas of the trestles by their total length. Trestle filling was kept in Item 8, in order to correspond with the accounting records.

The prices assigned to all classes of construction include all labor, materials and costs of transporting men and materials, train service, etc.

Item 12, Frogs and Switches, does not include cross-ties, which are included in Item 9.

Item 17, Telegraph Lines, was taken from the accounting records and 20% added to cover increase in prices, transportation of men, etc. The Great Northern does not own the telegraph lines entirely.

Table XIII summarizes the cost of reproduction, and gives also present value.

TABLE XIII.—COST OF REPRODUCTION AND PRESENT VALUE OF GREAT NORTHERN AS ESTIMATED BY H. P. GILLETTE.

		Reproduction. New.	Condition. Per cent.	Present Value.
1.	Engineering	$ 1,077,601	100.0	$ 1,077,601
2.	Right of way	17,105,692	100.0	17,105,692
3.	Clearing and grubbing	700,412	100.0	700,412
4.	Grading	9,619,811	110.0	10,581,792
5.	Tunnels	4,261,200	100.0	4,261,200
6.	Masonry (except in Item 8)	865,719	100.0	865,719
7.	Cribbing and bulkheading	375,779	22.0	82,672
8.	Bridges and culverts	3,850,986	78.2	3,011,471
9.	Ties	1,432,200	46.3	663,109
10.	Rails	3,929,480	80.0	3,143,584
11.	Track fastenings	767,279	80.0	613,823
12.	Frogs and switches	82,640	80.0	66,112
13.	Ballast	879,960	100.0	879,960
14.	Tracklaying and surfacing	668,360	100.0	668,360
15.	Fencing right of way	80,371	54.5	43,802
16.	Crossings, cattle guards, etc.	185,774	90.0	167,197
17.	Telegraph lines	56,622	80.0	45,298
18.	Transp. dept. bldgs	983,535	89.5	880,265
19.	Road dept. bldgs	95,958	76.0	72,928
20.	Roundhouses and shops	300,805	83.5	251,173
21.	Fuel and water stations	238,200	80.0	190,560
22.	Shop tools and machinery	181,280	65.0	117,832
23.	Grain elevators	125,200	79.0	98,908
24.	Docks and wharves	648 869	79.0	512,606
25.	Other bldgs. and structures	241,182	85.0	205.004
26.	Snow protection	216,992	72.4	157,103
27.	Legal and general expense	307,886	100.0	307,886
28.	Interest during constr	1,608,705	100.0	1,608,705
29.	Stores on hand	360,904	100.0	360,904
	Total of items 1 to 29	$51,249,402		$48,741,678
30.	Equipment	4,569,624	70.33	3,213,747
	Grand total	$55,819,026		$51,955,425

In arriving at an estimate of the Present Value, or second-hand value, of the property, Mr. Gillette determined the average age of each class of structures, as explained in his report to the Railroad Commission (see *Engineering-Contracting*, April 7, 1909). Then an annual depreciation was determined from a study of the records. For example, the average age of existing trestles was 4.2 years, and the annual depreciation was taken at 10%; hence the present ndition was 100% — 4.2 × 10% = 58%.

Table XIV gives average ages and annual depreciations.

TABLE XIV.

	Age years.	Annual deprec. per cent.	Present condition per cent.
Cribbing and bulkheading	4.2	10.0	58.0
Howe truss bridges	5.0	10.0	50.0
Log culverts	9.4	6.0	41.6
Timber culverts	13.0	6.0	12.0
Box drains	13.0	6.0	12.0
Ties	4.3	12.5	46.3
Rails, track fastenings, etc.	8.0	2.5	80.0
Fences	6.5	7.0	54.5
Transportation dept. bldgs.	3.5	3.0	89.5
Road dept. bldgs.	8.0	3.0	76.0
Roundhouses and shops	5.5	3.0	83.5
Fuel and water stations	...	...	80.0
Shop tools and machinery	3.5	10.0	65.0
Grain elevators	7.0	3.0	79.0
Docks and wharves	7.0	3.0	79.0
Other buildings	5.0	3.0	85.0
Snow sheds	6.9	4.0	72.4

The rate of depreciation of Fuel Stations was assumed at 3%; Water Stations at 2½%, the latter being lower because so much of the value exists in piping, reservoirs, etc.

Equipment depreciation was put at 3.6% per annum.

All other items were regarded as having suffered no depreciation. Grading was regarded as having actually appreciated 10% in value, due to the "seasoning" of the roadbed. This is equivalent to $1,280 per mile, which was regarded as a liberal allowance for expenditures in track maintenance during the first few years after construction, which might properly be charged to construction, although, in fact, they never are so charged in the company. books. It also provides for the increased value of the roadbed due natural settlement.

The actual cost of the equipment of the entire Great Northern Ry. system, as determined from the accounting records, was as follows, up to June 30, 1906:

Locomotives	$10,020,193.14
Passenger cars	4,070,424.68
Freight cars	20,356,142.73
Work and miscellaneous	1,487,062.67
Total	$35,933,823.22
Spokane Falls and Northern	190,742.00
Grand total	$36,124,565.22

The actual original cost of the Spokane Falls & Northern equipment, as purchased by the Great Northern Ry., was not available, but was estimated to be $190,742, composed of the following items:

Locomotives	$ 71,500.00
Passenger cars	33,500.00
Freight cars	69,340.00
Work and miscellaneous	16,402.00
Total	$190,742.00

To arrive at the cost of reproducing the equipment new, present (1906) prices, were assumed and applied to all the locomotives and cars. This showed an increase of cost of about 15%, hence it was decided to add 15% to the original cost (as shown by the accounting records) to obtain the cost of reproduction new.

With the exception of the locomotives, the entire equipment was then prorated to the state of Washington on the ratio of the car mileage of the entire system to the car mileage of Washington. The work equipment was prorated on the basis of the miles of road operated.

The cost of reproduction and the present value of the equipment for the state of Washington were estimated to be as follows:

	Cost of Reproduction	Present Value.
Locomotives	$1,334,740.70	$ 876,779.33
Passenger cars	715,395.92	494,404.42
Freight cars	2,320,036.29	1,695,410.98
Work and miscellaneous	199,451.19	147,152.36
Total	$4,569,624.10	$3,213,747.09

The present value (second-hand value) was not ascertained by a field inspection, which is practically impossible of satisfactory accomplishment anyway, but by determining the average age of each kind of equipment and multiplying that age in years by 3.6%, to arrive at the percentage of depreciation suffered.

Mr. Gillette's studies of the equipment records indicated to him that the average locomotive or car could not be expected to have a life exceeding 28 years, and that it would therefore be liberal to the railway to allow an annual depreciation of only 3.6% in arriving at the present value. He selected the straight line formula, rather than the sinking fund formula, for estimating depreciation.

In determining the average age of locomotives the standard price of each locomotive was multiplied by its age. The sum of these products was divided by the total cost of the locomotives to secure the average age. It would be manifestly incorrect to use the actual average age obtained by dividing the sum of the ages by the total number of locomotives, for locomotives differ so in value that the "weighted average" must be obtained. In like manner the age of all rolling stock was determined. It will be noted that there was an average depreciation of 29.67% (since the condition was 70.33%). Hence the average weighted age of all equipment was $29.67 \div 3.6 = 8.24$ years. The rolling stock on the Spokane Falls & Northern was all 10 years old, and on the rest it was as follows:

Locomotives	9.5 years
Passenger cars	8.5 "
Freight cars	7.4 "
Work and miscellaneous	7.0 "

The cost of reproduction of the Great Northern, per "mile of line," is given in Table XV.

TABLE XV.—COST OF REPRODUCTION OF GREAT NORTHERN RY. IN WASHINGTON, AS ESTIMATED BY H. P. GILLETTE.

		Per mile of line.*
1.	Engineering	$ 1,406
2.	Right of way	22,317
3.	Clearing and grubbing	914
4.	Grading	12,550
5.	Tunnels	5,559
6.	Masonry	1,030
7.	Cribbing and bulkheading	489
8.	Bridges and culverts	5,024
9.	Ties	1,870
10.	Rails	5,126
11.	Track fastenings	1,001
12.	Frogs and switches	107
13.	Ballast	1,148
14.	Tracklaying and surfacing	872
15.	Fencing right of way	105
16.	Crossings, cattle guard and signs	242
17.	Telegraph lines	74
18.	Transportation department buildings	1,284
19.	Road department buildings	125
20.	Roundhouses and shops	391
21.	Fuel and water stations	310
22.	Shop tools and machinery	236
23.	Grain elevators	163
24.	Docks and wharves	845
25.	Other buildings and structures	314
26.	Snow protection	282
27.	Legal and general expense	401
28.	Interest during construction	2,098
29.	Stores on hand	470
	Total of Items 1 to 29	$66,753
30.	Equipment	5,950
	Grand total	$72,703

*There are 1.244 miles of track per mile of line; hence multiply by 0.8 to get cost per mile of track.

During the fiscal year ending June 30, 1906, there were 479,-847,387 ton-miles of freight carried over the Great Northern within the state of Washington. The freight car mileage was 33,428,695 car-miles in Washington, or 9.681% of the car-mileage of the entire Great Northern system.

Cost of the Northern Pacific Railway (1,645 Miles) in the State of Washington.*—This issue contains data relating to the Northern Pacific Ry., data that were submitted as exhibits by Mr. H. P. Gillette in his testimony at the hearings before the Railroad Commission, but not printed in the "findings," which contain only the conclusions as to costs reached by the commission after hearing all the evidence.

Work was begun on the Northern Pacific in Washington in 1879, and the major part of the construction of the main line was done in the early 80's. The task of ascertaining the original cost of the Northern Pacific was complicated not only by the age of the rec-

*_Engineering-Contracting,_ Jan. 12, 1910.

ords but by the purchase of a number of important branch lines. The purchase prices were available, but it was exceedingly desirable to arrive at the actual cost to the builders of those branches. This was determined with considerable accuracy by securing construction quantities from old engineering records and applying prices current at the time of construction. The total original cost of main line and branches in Washington was found to be about $64,000,000, including improvements and betterments. Of this total 80% was ascertained with great accuracy from the accounting records. Of the remaining 20% fully half was determined with almost as great accuracy from old engineering records, leaving only about 10% to be estimated by field inspection.

It has been repeatedly stated that the original cost plus improvements can be ascertained for very few railways in America. Doubtless this assertion has deterred other railway commissions from even attempting to secure the original cost. The facts are, however, that of the entire railway values in Washington, not much more than 5% were such that the original cost plus improvements could not be found. Mere age of construction has less to do with the difficulty of arriving at original costs than is commonly supposed. The greatest difficulty exists where purchases of lines have been made without transfer of the construction ledgers from the original owners to the purchasers. In many instances such transfers of ledgers are made, and in nearly all cases transfers of cross section books and other engineering records are made. The importance of securing the original itemized costs plus itemized costs of improvements cannot be overestimated. The conflicting testimony of experts in court is the bane of a judge's life, but with actual original costs as a basis there is not great difficulty in determining costs of reproduction, for wages and prices are a matter of record and the increase or decrease in the value of any item of railroad construction is readily ascertained.

The following is a summary of the mileage of the Northern Pacific railway in Washington up to June 30, 1906:

	Miles.
Main line	658.73
Branch lines (incl. Wash. and Col. Rivers)	986.53
Total lines	1,645.26
Second track, main line	41.65
Spurs	117.59
Yard tracks and sidings	400.75
Total track	2,205.25

In the findings of the Railroad Commission the following mileage was assigned to the Northern Pacific:

	Miles.
Main line	687.68
Branches and spurs	941.74
Total lines	1,629.42

However, we shall use the mileage determined by Mr. Gillette—namely: 1,645 miles of line—since the following costs are based upon that mileage.

The original cost of the Northern Pacific in Washington plus improvements and betterments up to June 30, 1906, as determined by Mr. Gillette, was as given in Table XVI. In using the last column of this table it should be remembered that there were 1.34 miles of all tracks to each "mile of line"; hence to arrive at the cost per mile of track, divide the items in the last column by 1.34.

TABLE XVI.—ORIGINAL COST OF THE NORTHERN PACIFIC RAILWAY IN WASHINGTON, PLUS IMPROVEMENTS.

(1,645 miles of line.)

	Total.	Per mile.
1. Engineering	$ 2,907,344.26	$ 1,768
2. Right of way	1,796,272.00	1,092
3. Real estate	1,360,895.38	827
4. Clearing and grubbing	1,213,770.19	738
5. Grading	15,589,712.88	9,479
6. Tunnels	974,519.99	590
7. Bridges, trestles and culverts	7,879,328.94	4,790
8. Masonry	156,823.46	95
9. Ties	2,278,007.25	1,385
10. Rails	8,520,625.03	5,182
11. Track fastenings	1,063,620.96	647
12. Frogs and switches	255,243.07	155
13. Tracklaying and surfacing	1,669,691.18	1,015
14. Ballast	1,524,759.29	929
15. Station buildings and fixtures	1,477,207.49	897
16. Engine houses and turntables	246,663.97	150
17. Engine and car shops	849,340.77	516
18. Shop machinery and tools	294,507.95	179
19. Water stations	325,042.66	198
20. Fuel stations	79,544.48	47
21. Fencing right of way	273,067.50	166
22. Snow fences, etc	130,494.72	79
23. Stock yards	31,064.11	19
24. Crossings, cattle guards and signs	101,860.54	62
25. Interlocking and signal apparatus	44,706.61	27
26. Docks, wharves and coal bunkers	1,015,566.29	617
27. Transfer boats and barges	31,662.70	19
28. Section and tool houses	122,352.50	74
29. Miscellaneous structures	1,179,108.09	717
30. Telegraph lines	207,361.48	126
31. Transportation charges and rent of equipment	1,756,796.39	1,068
32. Operating expenses	261,910.26	159
33. Construction equipment	63,743.75	39
34. General expense	640,744.02	390
35. Interest and discount	7,173,190.53	4,360
36. Legal expense	3,009.24	2
37. Undistributed expense	480,212.62	292
Total	$63,979,772.61	$38,895
38. Equipment (rolling stock)	11,478,121.38	6,978
Grand total	$75,457,893.99	$45,873

Of this $63,979,772 cost of construction, $5,896,735 was spent for "improvements and betterments" between the years 1896 and 1906. The corresponding improvement expenditures prior to that time (charged to "Construction B") were $2,951,972, making a total of $8,848,707 spent for improvements.

It will be noted that Item 1, Engineering, amounts to nearly 5% of the total cost exclusive of equipment. This very high percentage was due to several factors. The explorations for a pass through the Cascade Mountains were made at an early date when little was definitely known about their topography and that exploration alone cost $300,000. The engineering on the early branch lines cost 6% of the $11,400,000 spent in building them, due in part to slow progress of work in those early days. A very considerable part of the early Northern Pacific work was done by company labor, which added not only to the expenditures for engineering and supervision, but also made the entire cost of the work greater than it would have been had it been done by contract.

Items 2 and 3 are small, because nearly all the right of way was given by the government. But as a matter of fact it should be a trifle higher than given in Table XVI, to provide for the unascertainable original cost of right of way of about 350 miles of branch lines.

Item 31, Transportation Charges and Rent of Equipment, relates to the book charges for hauling construction materials over the N. P. lines. Under a proper system of accounting this item would have been distributed to the materials themselves.

Item 32, Operating Expense, relates to the cost of operating freight and passenger trains over the lines before they were formally transferred to the operating department.

Item 34, General Expense, was practically 1% of the total construction cost.

On the early construction work, involving some $30,000,000, this item of general expense was nearly 1¾%.

Item 35, Interest and Discount, is inordinately high. It consists mostly of discount on the bonds. In fact the first $22,400,000 expended, more than $5,900,000 was charged to interest and discount, or nearly 27% of the total. Hence no general conclusions can be drawn from this item.

Item 36, Legal Expanse, does not appear in any of the accounts except for a small branch line, where it amounted to nearly 1 per cent of the cost of that branch.

Item 37, Undistributed Expense, relates to certain items which were so entered that they could not be prorated to Washington under any definite item, and were consequently grouped here.

The cost of reproducing (new) the Northern Pacific Ry. in Washington, as estimated by Mr. Gillette, is given in Table XVII, the values of right of way and land being those finally determined by the Railroad Commission.

TABLE XVII.—COST OF REPRODUCING THE NORTHERN PACIFIC RAILWAY IN WASHINGTON, AS ESTIMATED BY H. P. GILLETTE.
(1,645 miles of line.)

1. Engineering, 5% of Items 3 to 27.............$	2,510,580.23
2. Right of Way, etc.:	
Terminal land, Seattle	13,038,176.50
Terminal land, Tacoma	7,638,006.00
Terminal land, Spokane	5,306,465.00
Terminal land, Everett	366,530.00
Terminal land, Bellingham	215,330.00
Right of way and other station grounds............	6,298,364.50
Total right of way, etc...........................$	32,862,872.00
3. Clearing and Grubbing:	
Clearing, 9,445 acres, at $100.00...................$	944,500.00
Grubbing, 16,542 stations, at $22.00................	330,840.00
Extra trees cut, 4,942, at $2.00....................	9,964.00
Six branch lines (from acctg. records)..............	117,811.04
Improvements (from acctg. records).................	24,069.48
Total clearing and grubbing......................$	1,427,184.52
4. Grading:	
Earth excavation, 18,566,958 cu. yds., at $0.22.......$	4,084,730.76
Earth embank. (barrow), 3,265,120 cu. yds., at $0.22.	718,326.20
Unclassified, 318,512 cu. yds., at $0.50.............	159,256.00
Cement gravel, 3,483,838 cu. yds., at $0.40..........	1,393,535.20
Loose rock, 1,321,720 cu. yds., at $0.50.............	660,860.00
Solid rock, 1,735,503 cu. yds., at $1.10..............	1,909,053.30
Overhaul, 13,767,359 cu. yds. 100 ft., at $0.01.......	137,673.59
Riprap, 186,064 cu. yds., at $1.10..................	204,670.40
Slope wall, 3,350 cu. yds. at $2.50...................	8,375.00
Log cribs, 882,632 lin. ft. logs, at $0.16............	141,221.12
Timber cribs, 127,774 ft. B. M., at $26.00...........	3,322.12
Six branch lines (cost from acctg. records)..........	1,113,697.75
S. L. S. & E. (estimated from field inspection)....	88,000.00
Improvements and betterments (from acctg. records).	1,988,673.81
Total grading ....$	12,543,395.25
5. Tunnels:	
Stampede, 9,844 lin. ft. (masonry lined), at $180.00..$	1,771,920.00
Seattle, one-half interest, 5,141 (dbl. track in earth), at ½ of $360.00................................	925,380.00
Other tunnels lined with concrete, 2,570 ft., at $110.00	282,700.00
Other tunnels lined with timber, 2,329 ft., at $70.00..	163,030.00
Total tunnels ....$	3,143,030.00
6. Bridges, Trestles and Culverts:	
Howe Tusses and Combination.	
30-ft. spans, 1 at $1,200.00.......................$	1,200.00
50-ft. spans, 4 at $1,600.00........................	6,400.00
60-ft. spans, 8 at $1,800.00........................	14,400.00
70-ft. spans, 1 at $2,000.00........................	2,000.00
80-ft. spans, 3 at $2,300.00........................	6,900.00
90-ft. spans, 1 at $3,000.00........................	3,000.00
100-ft. spans, 15 at $4,000.00........................	60,000.00
110-ft. spans, 1 at $4,500.00........................	4,500.00
120-ft. spans, 3 at $5,500.00........................	16,500.00
130-ft. spans, 1 at $6,200.00........................	6,200.00
140-ft. spans, 5 at $7,000.00........................	35,000.00
150-ft. spans, 19 at $7,500.00........................	142,500.00
13 miscellaneous spans (2,390 lin. ft. at $60.00)....	143,400.00
8 draw spans, 1,625 lin. ft. at $60.00..............	97,500.00
Total Howe trusses and combination spans....$	539,500.00

Pile and frame trestles (44,130 M at $30,000, and 1,304,533 lin. ft. piles at 0.25; av. height trestle 19 ft.), 168,978 lin. ft. at $10.50	1,774,269.00
Trestles filled with earth (139,862 lin. ft.), 5,988,784 cu. yds. at $0.20	1,197,756.80
Steel Bridges:	
Spokane River at Trent $	40,000.00
Snake River, Ainsworth	1,100,000.00
Columbia River, Kennewick	500,000.00
Tacoma Channel	105,000.00
Chehalis River	100,000.00
Walla Walla River, W. & C. R.	43,190.00
Three plate girders (260 ft.) and concrete ret. wall (350 ft.), N. & C. R.	30,200.00
Steel in other bridges, 19,516,343 lbs. at 0.0475	927,026.44
Masonry abutments and piers for 215 spans	537,500.00
Total steel bridges $	3,382,916.44
Culverts:	
Log culverts, 264,943 lin. ft. logs, at $0.16 $	42,390.88
Timber culverts, 5,015,024 ft. B. M. at $26.00	130,390.62
Box drains, 336,720 ft. B. M. at $26.00	8,754.72
Total log and timber culverts $	181,536.25
Concrete arch, 11,510 cu. yds. at $9.00	103,590.00
Stone drains, 6,731 cu. yds. at $8.00	53,848.00
Total masonry culverts $	157,438.00
Vitrified Pipe:	
4-in., 62 lin. ft. at $0.25 $	15.50
10-in., 50 lin. ft. at 0.45	22.50
12-in., 1,229 lin. ft. at 0.50	614.50
15-in., 226 lin. ft. at 0.75	169.50
16-in., 137 lin. ft. at 0.80	109.60
18-in., 3,929 lin. ft. at 1.30	5,107.70
20-in., 168 lin. ft. at 1.70	285.60
22-in., 109 lin. ft. at 2.00	218.00
24-in., 24,895 lin. ft. at 2.60	664,727.00
30-in., 2,845 lin. ft. at 3.50	9,957.50
36-in., 276 lin. ft. at 4.50	1,242.00
Total vitrified pipe culverts $	682,469.40
Cast-Iron Pipe:	
6-in., 300 lin. ft. at $1.00 $	300.00
8-in., 24 lin. ft. at 1.50	36.00
12-in., 892 lin. ft. at 3.00	2,676.00
14-in., 27 lin. ft. at 3.50	94.50
16-in., 732 lin. ft. at 3.75	2,745.00
18-in., 5,095 lin. ft. at 4.00	20,380.00
20-in., 889 lin. ft. at 4.75	4,222.75
24-in., 28,411 lin. ft. at 6.00	170,466.00
30-in., 2,432 lin. ft. at 7.00	17,024.00
36-in., 4,458 lin. ft. at 9.00	40,122.00
42-in., 663 lin. ft. at 13.00	8,619.00
48-in., 1,026 lin. ft. at 18.00	18,468.00
54-in., 516 lin. ft. at 21.00	10,836.00
60-in., 198 lin. ft. at 25.00	....
36-in. corrugated iron, 900 ft. at $3.00	4,950.00
Total iron pipe culverts	2,700.00
Masonry walls, etc.	303,639.25
Total bridges, trestles and culverts $	7,776,348.11

7. Ties:

(2,205.24 miles at 3,000), 6,615,750, at $0.50.........$	3,307,875.00

8. Rails:

221,367 tons at $40.00.............................$	8,854,680.00

9. Track Fastenings:

Spikes (6,500 lbs. per mi.), 14,334,125 lbs. at $0.028..$	401,355.50
Angle bars (17,600 lbs. per mi.), 38,812,400 lbs., at $0.025	970,310.00
Bolts (1,800 lbs. per mi.), 3,969,450 lbs. at $0.032...	127,022.00
Rail braces, 838,950 at $0.10......................	83,895.00
Tie plates, 1,525,000 at $0.08.....................	122,000.00
Total track fastenings........................$	1,704,582.90

10. Frogs and Switches:

Switches, 2,850 at $80.00..........................$	228,000.00

11. Ballast:

1,645 miles at $1,000.00...........................$	1,645,000.00
560 miles at $600.00.............................	336,000.00
Total ballast ....$	1,981,000.00

12. Tracklaying and Surfacing:

2,205.25 miles at $700.00..........................$	1,543,675.00

13. Fencing Right of Way:

From accounting records plus 20%.................$	227,682.00

14. Snow Fences and Sheds:

From accounting records plus 20%.................$	156,595.00

15. Crossings, Cattle Guards and Signs:

From accounting records plus 20%..................$	122,232.00

16. Telegraph Lines:

From accounting records plus 20%.................$	248,835.00

17. Station Buildings and Fixtures:

Seattle terminal station (½ interest)................$	280,000.00
110 combination depots (frame), 167,062 sq. ft. at $1.50	250,593.00
100 passenger depots (frame), 121,684 sq. ft. at $1.25	152,105.00
Spokane passenger depot (brick), 8,050 sq. ft. at $4.00	32,200.00
31 freight depots (frame), 591,050 sq. ft. at $1.00...	591,050.00
3 freight depots (brick), 81,320 sq. ft. at $1.50......	121,980.00
Warehouses (frame), 376,741 sq. ft. at $1.40..........	527,437.40
720 wood platforms, 1,006,790 sq. ft. at $0.10........	100,679.00
15 cinder platforms, 26,492 sq. ft. at $0.06...........	1,589.52
2 cement platforms, 34,631 sq. ft. at $0.15..........	5,194.65
198 water closets, 10,666 sq. ft. at $1.00...........	10,666.00
Track scales, 28 at $1,300.00.......................	36,400.00
Total station buildings......................$	2,109,894.57

18. Engine Houses and Turntables:

8 engine houses (frame), 27,686 sq. yds. at $0.75....$	20,764.50
Engine houses (frame), 20 stalls $900.00...........	18,000.00
Engine houses (brick), 71 stalls at $1,500.00.......	106,500.00
Turntables, 28 at $2,800.00........................	78,400.00
6 ash pits, 277 lin. ft. at $15.00....................	4,155.00
Total engine houses and turntables...........$	227,819.50

Pile and frame trestles (44.[illegible] (frame), 114,523 1,304,533 lin. ft. piles [illegible] 19 ft.), 168,978 [illegible] ....$	57,261.50
[illegible] houses (brick), 299,685 [illegible] and car [illegible]	869,086.50
Trestles filled [illegible] cu. yds. [illegible] 2 at $1,500.00	3,000.00
Steel [illegible] Transfer tables [illegible] coal, wood, oil and store houses, 20,245 sq. ft. at $0.50	10,122.50
Spok[illegible] 2 bins, 2,053 sq. ft. at $0.25	513.25
Total engine and car shops ....$	939,983.75
20. Shop Machinery:	
From accounting records plus 20% ....$	353,408.00
21. Water Stations:	
91 tanks, 41 pump houses, etc. (from accounting records plus 20%) ....$	390,050.00
22. Fuel Stations:	
From accounting records plus 20% ....$	95,453.00
23. Stock Yards:	
63 yards, 603,397 sq. ft. at $0.05 ....$	30,169.85
24. Interlocking and Signal Apparatus:	
From accounting records plus 20%	53,648.00
25. Docks, Wharves and Coal Bunkers:	
From accounting records plus 20% ....$	1,216,680.00
26. Section and Tool Houses:	
124 section houses, 89,866 sq. ft. at $1.25 ....$	112,332.50
80 bunk houses, 29,430 sq. ft. at $0.70	20,601.00
147 tool houses, 27,839 sq. ft. at $0.50	13,919.50
Total section and tool houses ....$	146,853.00
27. Miscellaneous Structures:	
From accounting records plus 20% ....$	1,382,530.00
28. Legal and General Expense:	
1% of Items 3 to 27 inclusive ....$	502,116.04
29. Interest During Construction:	
5% of Items 1 to 28 (except Item 2) ....$	2,661,215.04
30. Stores on Hand ....$	580,677.00
Total of Items 1 to 30 inclusive ....$	89,279,064.76
31. Equipment:	
Locomotives ....$	4,242,950.51
Passenger	1,447,593.23
Freight	8,040,254.92
Work and miscellaneous	603,578.55
Total equipment ....$	14,334,377.21
Grand total of Items 1 to 31 inclusive ....$	103,613,441.97

It will be noted that Item 1, Engineering, was estimated at 5%, instead of the 3½% which was used for the Great Northern. Since engineering had actually cost the Northern Pacific 5%, Mr. Gillette considered it fair to allow that amount, particularly in view of the fact that there was a large mileage of cheap branch lines where the item of engineering would form a larger percentage than on main line construction. The Railroad Commission, however, adopted a

uniform 3½% for all the railways in the state as a fair allowance for engineering.

Item 2, Land, does not include any land not actually used or needed for railway purposes in the immediate future. The Northern Pacific Ry. has a right of way 400 ft. wide on much of its line, given to it by the government. The Railroad Commission allowed a 100 ft. strip as being all that is actually needed for railway purposes, except in towns and cities. In addition to the lands owned and used for terminals, there was land of the following value, which was not included in Item 2 because it is not needed for railway purposes at present:

Spokane	$ 1,194,156
Tacoma	4,980,417
Seattle	9,250,000
Total	$15,424,573

The value of the right of way land not needed for railway purposes was determined to be $913,184, and is not included in Item 2. Item 4, Grading, is equivalent to the following yardage per mile of line:

	Cu. yds. per mile.
Earth excavation	11,325
Earth embankment (borrow)	1,990
Unclassified	195
Cement gravel	2,125
Loose rock	805
Solid rock	1,055
Total	17,495
6 branch lines (unclassified)	1,700
S. L. S. & E. (unclassified)	130
Improvements (unclassified)	4,545
Trestles filled (Item 6)	3,650
Grand total	26,520

The items of yardage in the "6 branch lines" and of yardage in "improvements" are estimated by assuming that the unclassified yardage on these branch lines cost 40 cts. per cu. yd. and that the yardage in improvements cost 30 cts. per cu. yd. Since most of the improvement yardage was bank widening, the lower unit price for this unclassified work is justified. By referring to our issue of Dec. 8 it will be seen that the yardage per mile on the Great Northern was 28,570 cu. yds. per mile.

Table XVIII gives a summary of Mr. Gillette's estimate of the cost of reproduction (new) and the present value (second hand) of the Northern Pacific in Washington. The annual rates of depreciation of the different classes of structures and of equipment were the same as those used in calculating the present value of the Great Northern.

TABLE XVIII.—COST OF REPRODUCTION AND PRESENT VALUE OF THE NORTHERN PACIFIC RY. IN WASHINGTON.

(1,645 Miles.)

	Cost of reproduction new.	Condition per cent.	Present value.
1. Engineering	$ 2,510,580	100.0	$ 2,510,580
2. Right of way, etc..........	32,862,872	100.0	32,862,872
3. Clearing and grubbing.....	1,427,185	100.0	1,427,185
4. Grading	12,543,395	110.0	13,797,735
5. Tunnels	3,143,030	100.0	3,143,030
6. Bridges, trestles and culverts	7,776,348	84.7	6,586,567
7. Ties	3,307,875	50.0	1,653,938
8. Rails	8,854,680	80.0	7,083,744
9. Track fastenings	1,704,583	80.0	1,363,666
10. Frogs and switches........	228,000	80.0	182,400
11. Ballast	1,981,000	100.0	1,981,000
12. Tracklaying and surfacing..	1,543,675	100.0	1,543,675
13. Fencing right of way......	227.682	55.0	125,225
14. Snow fences and sheds....	156,595	72.0	112,748
15. Crossings, cattle guards and signs	122,232	55.0	67,228
16. Telegraph lines	248,835	75.0	186,626
17. Station building and fixtures	2,109,895	81.5	1,727,769
18. Engine houses and turntables	227,819	68.2	155,373
19. Engine and car shops......	939,984	66.4	624,169
20. Shop machinery	353,408	65.0	299,715
21. Water stations	390,050	65.5	255,483
22. Fuel stations	95,453	77.5	73,976
23. Stock yards	30,170	45.5	13,727
24. Interlocking and signal apparatus	53,648	85.0	45,601
25. Docks, wharves and coal bunkers	1,216,680	75.0	912,510
26. Section and tool houses....	146,853	61.0	89,580
27. Miscellaneous structures...	1,382,530	61.0	843,343
28. Legal and general expense..	502,116	100.0	502,116
29. Interest during construction	2,661,215	100.0	2,661,215
30. Stores on hand...........	530,677	100.0	530,677
Total of Items 1 to 30....$	89,279,065	.....	$83,363,454
31. Equipment	14,334,377	67.5+	9,677,947
Grand total...........$	103,613,442	.....	$93,041,401

TABLE XIX.—COST OF REPRODUCTION OF THE NORTHERN PACIFIC IN WASHINGTON.

		Per mile of line.*
1.	Engineering	$ 1,526
2.	Right of way, etc.	19,980
3.	Clearing and grubbing	867
4.	Grading	7,626
5.	Tunnels	1,911
6.	Bridges, trestles and culverts	4,728
7.	Ties	2,011
8.	Rails	5,384
9.	Track fastenings	1,036
10.	Frogs and switches	139
11.	Ballast	1,206
12.	Tracklaying and surfacing	938
13.	Fencing right of way	138
14.	Snow fences and sheds	95
15.	Crossings, cattle guards and signs	74
16.	Telegraph lines	151
17.	Station buildings and fixtures	1,283
18.	Engine houses and turntables	138
19.	Engine and car shops	571
20.	Shop machinery	215
21.	Water stations	237
22.	Fuel stations	58
23.	Stock yards	18
24.	Interlocking and signal apparatus	33
25.	Docks, wharves and coal bunkers	740
26.	Section and tool houses	89
27.	Miscellaneous structures	840
28.	Legal and general expense	305
29.	Interest during construction	1,618
30.	Stores on hand	322
	Total of Items 1 to 30	$54,277
31.	Equipment	8,715
	Grand total	$62,992

*There are 1.34 miles of track per mile of line.

The actual cost of the equipment on the entire Northern Pacific system, up to June 30, 1906, was as follows:

Locomotives	$12,977,823.23
Passenger	5,074,739.99
Freight	21,436,740.43
Work and miscellaneous	1,904,185.11
Trust equipment	3,032,526.48
Discount and commission	939,858.42
Total equipment	$45,365,882.66

The above does not include the equipment of the Washington and Columbia River Ry., which was estimated by Mr. Gillette to have cost as follows:

Locomotives	$ 60,000
Passenger	24,000
Freight	62,000
Work	1,200
Total	$147,200

The cost of the locomotives in Washington was based upon the cost of those actually used in that state. The cost of passenger and freight cars was apportioned to Washington according to car mileage. The cost of work equipment was apportioned according to mileage of railway line operated. On this basis the following costs were arrived at for the state of Washington:

	Original cost.	Cost reproduction.	Present value.
Locomotives	3,689,522	4,242,950	2,715,488
Passenger	1,598,184	1,447,593	868,556
Freight	5,665,564	8,040,255	5,668,380
Work and miscellaneous	524,851	603,579	425,523
Total	$11,478,121	$14,334,377	$9,677,947

The "cost of reproduction" was determined by adding 15% to the original cost to provide for increased prices. The "present value" was determined by deducting from the "cost of reproduction" a depreciation of 3.6% per annum.

In this connection it is interesting to note that the report of the Northern Pacific Ry. to the Interstate Commerce Commission for the fiscal year ending June 30, 1906, gave the value of the equipment at $32,044,260, or about 70% of its original cost. Mr. Gillette's estimate of the "present" value was 67.5% of the original cost, which shows that the Northern Pacific Ry. had charged off for depreciation only slightly less than Mr. Gillette has estimated.

It is also worthy of comment that many railway engineers have erred in their estimates of the cost of equipping railways, largely because they have taken the total cost of equipment given in the Interstate Commerce Reports and have divided it by the total mileage of railway lines. It has not been generally known that the costs given in the Interstate Commerce Commission reports are depreciated, or second hand, values.

In roughly estimating the probable cost of equipment of a steam railway line the proper method is obviously to base the estimate upon the ton-miles (or car-miles) of freight per year per mile of line. In *Engineering-Contracting*, June 19, 1907, the freight carried per mile of railway in America was shown to have been 830,000 ton-miles in 1904. Since the Northern Pacific carried 845,000 ton-miles in 1906 per mile of line in Washington, it may be regarded as nearly typical of the average American road, so far as freight is concerned. On the other hand, its passenger traffic is considerably less dense than that of the average American road. It is safe to say, therefore, that the cost of the equipment of the Northern Pacific is fairly typical of the average railway in America. Roughly speaking, then, the cost of equipment of an American railway is $10 per 1,000 ton-miles carried per annum per mile of line.

During the fiscal year ending June 30, 1906, there were 1,390,064,-467 ton-miles of freight carried over the Northern Pacific within the state of Washington, or 845,000 ton-miles per mile of line. This was almost 50% more per mile of line than was carried by the Great Northern, which accounts for the higher cost of the Northern Pacific equipment per mile of line.

In drawing conclusions relative to the probable average cost of railway lines throughout the country, serious errors have been made by considering only the costs in one or two states. It will be noted that the cost of terminal lands in Washington is enormous when charged entirely to the road mileage within that state. In the findings of the Washington Railroad Commission it was determined that 56.8% of the entire value of lands used by the whole Northern Pacific Ry. system exists in the state of Washington.

The Railroad Commission also determined that 62.3% of the entire cost of tunnels and 31.6% of the entire cost of bridges on the N. P. system is found in Washington.

These figures show clearly the rugged character of much of the country traversed by the N. P. in Washington. Unquestionably the cost of its lines in that state far exceeds the cost in any other state through which it passes. The same also is true of the Great Northern.

Cost of 500 Miles of the O. R. & N.—My appraisal of the Oregon Railroad and Navigation Co. lines in the state of Washington gave, briefly, the following results:

On June 30, 1907, there were 501 miles of single track main line and branches, and 68 miles of sidings and yard track. The construction period was from 1875 to 1899, but most of the mileage was built in the 80's.

The following was the original cost of construction per mile of single track main line and branches (501 miles):

	Per mile.
1. Engineering	$ 623
2. Superintendence and inspection	78
3. Right of way	400
4. Lands and depot grounds	1,884
5. Grading	6,603
6. Clearing and grubbing	65
7. Tunnels	260
8. Bridges, trestles and culverts	2,518
9. Ties	1,397
10. Rails	5,589
11. Track fastenings	684
12. Frogs and switches	68
13. Ballast	526
14. Tracklaying and surfacing	798
15. Fencing, crossings, cattle guards and signs	118
16. Telegraph lines	4
17. Station buildings and fixtures	345
18. Section houses	141
19. Engine houses and shops	190
20. Turntables	50
21. Shop machinery and tools	10
22. Water stations	265
23. Miscellaneous structures	39
24. Legal expenses	6
25. Interest and discount	575
26. General expense	106
27. Taxes	8
28. Miscellaneous, undistributed	581
Total original construction	$23,931
Betterments, undistributed	2,388
Grand total	$26,319

My estimate of the cost of reproduction new was as follows per mile of single track main line and branches (501 miles):

	Per mile.
1. Engineering (3½% of Items 2 to 21)	$ 706
2. Grading	6,886
3. Tunnels	260
4. Bridges, trestles and culverts	2,782
5. Ties	1,666
6. Rails	4,515
7. Track fastenings	919
8. Frogs and switches	76
9. Ballast	721
10. Tracklaying and surfacing	828
11. Fencing right of way	255
12. Crossings, cattle guards and signs	44
13. Interlocking and signal apparatus	48
14. Telegraph lines	30
15. Station buildings and fixtures	283
16. Shops, roundhouses and turntables	165
17. Shop machinery and tools	46
18. Water stations	166
19. Fuel stations	52
20. Storage warehouses	112
21. Miscellaneous structures	307
22. Taxes	8
23. Section equipment	22
24. Legal and general expense (1% of Items to to 22)	202
25. Interest (5% of Items 1 to 24)	1,055
26. Stores on hand	481
Total	$22,635
27. Right of way and terminal grounds	4,487
Total	$27,122
28. Equipment (rolling stock)	2,994
Grand total	$30,116

For a more detailed statement of the foregoing items, consult the files of *Engineering-Contracting*, year 1910.

Note that there were 68 miles of sidetracks in addition to the 501 miles of main line. Hence the above costs per mile of main line should be divided by 1.136 to ascertain the cost per mile of track.

Appraised Value of the Steam Railways of Wisconsin.*—In our issue of June 26, 1907, was published the appraised value of the railways of Wisconsin, as of June 30, 1903. The following is a brief summary of the last valuation, as of June 30, 1907, which was completed in December, 1908, under the direction of Prof. W. D. Pence, Engineer of the Wisconsin Tax Commission and of the Railroad Commission. Table I is a summary of the first and the last valuations.

**Engineering-Contracting*, Jan. 19, 1910.

Table XX.—Comparison Between First and Fifth Wisconsin Steam Road Valuations.

	—Valuation as of date.— June 30, 1903.	June 30, 1907.
Number of railroad properties included...	47	52
Total length, road mileage..............	6,656.88	7,090.39
Cost of reproduction:		
Property, new total....................	$205,760,519	$244,128,868
Cost of reproduction:		
Existing condition, total...............	169,758,518	196,239,314
Reproduction cost per mile of line:		
Property new	30,900	34,400
Present value per mile of line...........	25,500	27,700
Per cent condition....................	82.5	80.3

The mileage on June 30, 1907, was as follows:

Main line	6,519.69
Main line, joint, ½ interest..........................	9.80
Branch line	551.83
Branch line, joint, ½ interest.........................	9.07
Total main and branch line............................	7,090.39
Second track	431.57
Third track	40.62
Fourth track	35.54
Total "trackway"	7,598.12
Spurs and sidings..................................	2,523.33
Spurs and siding joint, ½ interest....................	52.83
Spurs and sidings joint, ⅓ interest...................	4.32
Spurs and siding joint, ⅔ interest....................	0.29
Crossovers	0.04
Grand total track..................................	10,178.93

The total appraised values, new and in present (depreciated) condition, as of June 30, 1907, are as in Table XXI.

Table XXI.—Valuation New and in Depreciated Condition of Wisconsin Railways.

	Cost of reproduction. New.	Present condition.
1. Right of way and station grounds....	$ 26,339,419	$ 26,339,419
2. Real estate	....	....
3. Grading	39,391,307	39,391,307
4. Tunnels	797,412	776,972
5. Bridges, trestles and culverts.........	18,616,486	14,688,887
6. Cross ties and switch ties............	11 181,399	5,826,021
7. Rails	30,111,358	24,605,740
8. Track fastenings....................	5,254,013	3,367,649
9. Frogs, switches and crossings........	1,179,056	743,079
10. Ballast	5,768,084	3,969,476
11. Track laying and surfacing..........	3,345,555	2,770,572
12. Fencing	1,611,775	826,512
13. Crossings, cattle guards and signs....	440,896	269,880
14. Interlocking and signal apparatus....	613,354	538,801
15. Telegraph lines....................	167,840	99,587
16. Telephone lines and distribution system	89,639	81,439
17. Station buildings and fixtures........	3,918,995	2,902,418
18. Shops and round houses, power houses and car barns..................	3,892,882	3,048,497
19. Tools	144,419	86,384
20. Water stations.....................	1,345,218	986,357
21. Fuel stations......................	466,745	351,432
22. Grain elevators....................	826,706	612,171
23. Warehouses	262,539	200,278
24. Docks and wharves.................	3,645,907	2,956,821
25. Miscellaneous structures....	2,106,101	1,409,949
26. Sub-stations	45,130	44,119
Totals of all the above items......	$161,562,235	$136,893,767

27. Engineering, superintendence, and legal expenses, 4.5% of all the above items	7,270,300	6,160,220
28. Locomotives	11,531,174	7,331,573
29. Passenger equipment	5,317,465	3,193,301
30. Freight equipment	30,944,348	20,479,648
31. Miscellaneous equipment	901,935	588,260
32. Ferries and steamships	....	....
33. Electric plants	161,476	146,114
34. Shop machinery and tools	1,573,000	1,186,369
Totals of all the above items	$219,261,933	$175,979,252
35. Freight on construction material, 0.7% of items 1.34	1,523,656	1,209,539
36. Interest during construction, 3%; Organization, [1], contingencies, 5.5%; in all, [2], of items 1.34	20,738,225	16,463,297
37. Stores and supplies on hand for use in Wisconsin	2,605,054	2,587,226
Totals	$244,128,868	$196,239,314

[1]1% and 1.5%.
[2]9.5% and 10%.

Includes dock property and all lines under construction.

Dividing each of the items in the first column of Table XXI by 7,090, we have the following cost per mile of roadbed:

	Per mile of roadbed.
1. Right of way, etc.	$ 3,714
2. Real estate	.....
3. Grading	5,554
4. Tunnels	112
5. Bridges, etc.	2,625
6. Ties	1,577
7. Rails	4,246
8. Track fastenings	741
9. Frogs, etc.	166
10. Ballast	813
11. Track laying and surfacing	472
12. Fencing	227
13. Crossings, etc.	62
14. Interlocking and signal	86
15. Telegraph	24
16. Telephone	13
17. Station buildings	553
18. Shops and roundhouses	548
19. Tools	20
20. Water stations	189
21. Fuel stations	66
22. Grain elevators	121
23. Warehouses	37
24. Docks and wharves	514
25. Miscellaneous structures	297
26. Substations	6
Total of above	$22,783

27.	Engineering	1,025
28.	Locomotives	1,625
29.	Passenger equipment	750
30.	Freight equipment	4,363
31.	Miscellaneous equipment	127
32.	Ferries, etc.	....
33.	Electric plants	23
34.	Shop machinery and tools	222
	Total of above	$30,918
35.	Freight on construction materials	215
36.	Interest during construction, contingencies, etc.	2,924
37.	Stores on hand	367
	Grand total	$34,424

Since there are 1.435 miles of track per mile of roadbed, each of the above items should be divided by 1.435 (or multiplied by 0.7) to obtain the cost per mile of track. For example, item 11, "Track laying and surfacing," is $472 per mile of roadbed, which is equivalent to 0.7 × $472 = $331 per mile of track, which, by the way, is an exceedingly low estimate of cost.

Cost per Mile of Railways in Wisconsin and Michigan.*—In the year 1900, Prof. Mortimer E. Cooley made an appraisal of all the steam railways in Michigan for the Board of State Tax Commissioners. A field inspection was made of every structure to determine its "present value" expressed as a percentage of its value now. About 33,000 freight cars were inspected for the same purpose. By examining records of transfer of lands it was decided to use a factor of 2 to 2¼ by which to multiply the market value of adjacent property to obtain its "value for railway purposes." It is a well-known fact that a railway usually pays two to three times the ordinary market value of land in securing its right of way.

Prof. Cooley did not secure the "original cost" of the railways, that is, he did not secure the cost as determined by an inspection of the railways' records; but he made his own estimate of the "cost of reproduction" under the then (1900) existing conditions as to prices, wages, etc. An examination of his estimate leads us to think that it was, in many items, much too low, even though he added 10% for contingencies. But the railways have, as yet, not fought the estimate, because it was made for taxation purposes, and the lower the estimate to the more to their liking.

The Wisconsin appraisal was made by Prof. W. D. Taylor for the State Board of Assessment. He began this work in June, 1903, and made his final report 18 months later. Prof. Taylor pursued much the same plan as that pursued by Prof. Cooley, except that he required the railways themselves to submit first their own estimates of the cost of reproduction, which he subsequently checked, adding 13½% to their appraisal. Of course the railways tried to keep their estimates as low as possible, for the reasons above given, and it is quite apparent that the estimates were too low, even after Prof. Taylor had added the 5½% for contingencies.

**Engineering-Contracting*, June 26, 1907.

TABLE XXII.—COST OF WISCONSIN AND MICHIGAN RAILWAYS.

Item.	—Cost of Reproduction—New.— —Wisconsin.— Percentage of total cost.	Cost per mile of main line and branches (6,657 mi.) year 1903.	—Michigan.— Percentage of total cost.	Cost per mile of main line and branches (7,813 mi.) year 1900.	Present value expressed as per cent of cost of reproduction—new. Wis.	Mich.
1. Engineering, supt. and legal.....	3.04	$ 940[2]	2.97	$ 776[8]	100.0	100.0
2. Right of way and station grounds	12.03	3,719	13.58	3,552	100.0	100.0
3. Real estate....................	0.00	0	0.42	113	.....	100.0
4. Grading	16.50	5,098	10.63	2,778	99.99	100.0
5. Tunnels	0.39	122	0.56	147	97.8	95.4
6. Bridges, trestles and culverts.....	7.67	2,372	3.93	1,027	73.6	78.8
7. Cross ties and switch ties......	4.95	1,529	5.46	1,426	51.7	53.9
8. Rails	12.21	3,773	14.05	3,674	78.7	76.1
9. Track fastenings	2.00	617	1.88	492	70.2	77.8
10. Frogs, switches and crossings....	0.48	151	0.72	188	65.2	71.0
11. Ballast	2.55	788	1.83	476	66.8	100.0
12. Tracklaying and surfacing.......	1.45	447	3.21	839	100.0	97.5
13. Fencing	0.73	225	1.36	353	48.1	58.8
14. Crossings, cattle guards and signs	0.17	52	0.30	78	56.1	70.4
15. Interlocking and signal apparatus	0.17	52	0.25	64	76.9	89.3
16. Telegraph and telephone lines...	0.06	19	0.13	33	52.7	52.0
17. Station buildings and fixtures...	1.54	476	2.01	526	70.7	75.8
18. Shops, roundhouses and turntables	1.38	428	1.05	276	71.5	68.2
19. Shop tools and machinery.......	0.65	201[1]	0.54	142[7]	70.8	79.7
20. Water stations	0.52	161	0.36	93	63.9	72.0
21. Fuel stations	0.17	54	0.15	39	65.5	66.2
22. Grain elevators	0.40	126	0.65	171	74.0	75.0
23. Warehouses	0.12	37	0.13	33	75.0	71.3
24. Docks and wharves..............	0.84	260	2.71	707	75.9	69.4
25. Miscellaneous structures..........	1.14	353	0.60	158	60.8	69.4
Total lands and structures.........	71.16	$22,000	69.48	$18,161		

26. Locomotives	4.35	$ 1,342	4.42	1,155	65.7	56.4
27. Passenger equipment	12.03	3,627	1.57	2,408	69.1	71.2
28. Freight equipment	11.75	3,630	9.67	2,527	65.7	69.4
29. Miscellaneous equipment	0.22	70	0.34	90	62.4	60.3
30. Ferries and steamships	0.00	0	0.84	221	0.0	63.5
31. Electric plants	0.03	9	0.05	12	75.7	96.8
32. Freight on construction material	0.62	193[3]	0.00	0	100.0	0.0
33. Interest during construction	2.67	825[4]	2.59	667[4]	100.0	100.0
34. Organization	0.89	275[5]	1.30	335[9]	100.0	100.0
35. Contingencies	4.90	1,512[6]	9.02	2,360[10]	100.0	82.3
36. Stores and supplies on hand	1.38	427	0.72	189	97.1	82.2
Total equipment, contingencies, etc.	28.84	8,910	30.52	7,974	.....	.....
Grand total per mile of roadbed	100.00%	$30,910	100.00%	$26,138	82.5%	81.4%
Total cost of all rys. in the state	$205,760,519		$204,191,091			

STATISTICS FOR WISCONSIN AND MICHIGAN RAILWAYS.

	Miles. Wisconsin.	Miles. Michigan.	Per cent. Wisconsin.	Per cent. Michigan.
Main line	6,280	7,082	67½%	65%
Branches	377	731	4	6¾
Total	6,657	7,813	71½	71¾
Second track	335	164	4	1½
Spurs and sidings	2,279	2,905	24½	26¾
Total	9,271	10,882	100	100

Notes:—

[1]Track tools were 0.06%, and shop tools and machines 0.58%.
[2]Engineering, superintendence and legal expenses assumed at 4½% of items 2 to 25 inclusive.
[3]This item should have been changed above to materials.
[4]Assumed at 3% of items 1 to 32. (Should be 1 to 25.)
[5]Assumed at 1% of items 1 to 32.
[6]Assumed at 5½% of items 1 to 32.
[7]It is not clear whether this item includes track tools—probably not.
[8]Engineering and superintendence assumed at 4%, and legal expenses at 1½% of items 2 to 25.
[9]Assumed at 1½% of items 1 to 32.
[10]Assumed at 10% of items 1 to 32.

Now that the state of Wisconsin has begun to use the appraised values of the railways as a basis for rate making, the shoe is on the other foot, and it is not unlikely that the railways will ultimately demand a new appraisal, just as some of the railways in Texas have already done.

The appraised values of the Wisconsin and Michigan railways are given in the reports of Prof. Taylor and Prof. Cooley in such form as to admit of ready comparison. Table XXII is presented herewith in the belief that it may be of use to many of our readers.

The column showing the percentage of cost of each item is particularly interesting. It will be noted that grading cost only 16.5% in Wisconsin and 10.6% in Michigan. To the average engineer grading seems such a very important item that a knowledge of its real relative importance becomes very instructive. Grading in the more rugged state of Washington is far more expensive per mile than in the states of Wisconsin and Michigan. Indeed, there is scarcely an item of cost in Washington that will not exceed the costs given in the accompanying tables.

In using these tables the reader is cautioned to bear in mind the fact that the costs are expressed in the "mile of line" as the unit, and not in the "mile of track." There are practically 1.4 "miles of track" in each of the two states per "mile of line."

It will be noted that the "mile of line" is here used as synonymous with the "mile of roadbed."

Prof. W. D. Taylor used the following method in appraising the "present value" of steel rails in Wisconsin lines. If the market value of new rails is $28 per ton, and the scrap value is $12, then the wearing value is $16. If inspection indicates that 40% of the life has been used up, the present condition of the rail is 60%, and its present value per ton is $12 + 60% of $16 = $21.60 per ton.

Mr. Taylor adds, however, that another point of view might be taken. If the price of new rails at the mills in Chicago is $28, and the scrap price at the mills is $14, and if the rail is used at a point 200 miles from Chicago, then the cost of transportation is $1 per ton. This would make the price of the new rail $29 delivered, and would reduce the value of the scrap rail to $13 at the place of removal. To lay the new rail would cost $2.50 per ton, making a total of $31.50 per ton in place. To take up and load the old rail would cost $1 per ton, making the net realization from its sale in Chicago but $12 per ton. In addition the old rail has lost 3 to 6% of its weight.

Mr. Taylor states that the Chicago and Northwestern Ry. expended $11 per mile of roadbed in preparing the cost data for some 1,800 miles of its road. But he does not state what the state of Wisconsin spent in reviewing these data submitted by the railways.

In the appraisal of the Michigan railways the following unit prices were used:

Earth (incl. overhaul), per cu. yd.	$ 0.30
Rails, new, per ton	28.00
Rails, scrap, per ton	12.00
Rails wearing value per ton	16.00
Ties (15 to 17 per 30 ft. rail), oak, each	0.55

Life of trestles was considered to be 10 years.
Life of telephone poles and cross-arms, 12½ years.
Copper wire depreciation:

	Per cent.
For 2 years and less than 3 years	2½
For 3 years and less than 5 years	5
For 5 years and less than 10 years	10
For 10 years and over (junk value)	20
Underground conduit, per year	2
Cable (aerial or underground), lead covered and rubber, per year	10
Switchboards, per year	10

It has been stated that the cost of appraising the Michigan railways was $50,000, or $6.40 per mile of roadbed; but the railways themselves spent an amount which is unknown.

Appraisal of the Railways of Minnesota.*—We had hoped to be able to present in this issue of *Engineering-Contracting* abstracts of the reports of the chief engineers of two railway commissions, namely the report of Mr. Dwight C. Morgan to the Railroad and Warehouse Commission of Minnesota and the report of Mr. Halbert P. Gillette to the Railroad Commission of Washington. Mr. Morgan's report was submitted Nov. 30, 1908, and has just been published. Mr. Gillette's report was submitted a year ago but its publication has been delayed.

The two reports present many interesting contrasts in methods used in attacking the same problem, and, for that reason as well as because they are the first appraisals ever made for railroad commissions as a basis for railroad rate making, it was desirable to present them simultaneously. However, there are so many of our readers who will be interested in the methods and data given in Mr. Morgan's report that we present a summary in this issue, as follows, condensing the explanations of methods into our own language.

Mr. Morgan began the appraisal of the Minnesota railways Jan. 15, 1906, and rendered his report Dec. 1, 1908, the work having occupied almost three years, during which time 7,596 miles of railways were appraised. The method of making the appraisal was essentially the same as that used by Mr. William D. Taylor, engineer of the Wisconsin Tax Commission, who made an appraisal of Wisconsin railways for taxation purposes.

This method is what might be called the co-operative method of appraisal, because the railway companies are asked to co-operate with the railway commission, and, indeed, are required to submit their own detailed estimate of costs to the commission. The theory is that the commission is thus saved much unnecessary labor, and has merely to check over the estimates of the railways. In practice, however, it is our opinion that the engineers of the railway commission must either accept the returns of the railways without

**Engineering-Contracting,* March 3, 1909.

question or else spend almost as much time and labor in checking the estimate as was originally made by the railways in preparing it.

Blank forms were furnished to all the railways, upon which they were required to enter their detailed estimates. Two estimates were required, one giving the "cost of reproducing the property *new*. The other giving the "present value of the physical properties." The "cost of reproduction" means the cost of reproducing the property *new*. The "present value" is the depreciated or second-hand value, ascertained by deducting depreciation from the "cost of reproduction."

The unit prices used by Mr. Morgan were the average prices for the year 1905. which, he states, were about an average of the prices for the five-year period ending June 30, 1907.

In estimating the various railway lines, sections of about 100 miles were taken, but the "terminal properties" in St. Paul, Minneapolis and Duluth were treated as separate sections.

In valuing the lands, Mr. Morgan did not wait for a report from the railways, but started an independent investigation at once. Special agents were appointed to ascertain the value of lands adjacent to all railway lines. These agents examined and noted more than 55,000 bona fide sales of property, involving considerations of $100,000,000, and representing 1,300,000 acres of land. To do so they examined the records of the transfer of property for several years prior to Jan. 1, 1900, for a distance of 1½ miles on each side of each railway line, using the official county records for information.

The figures thus ascertained were plotted on maps, which facilitated arriving at values per acre in any given section. This, in our judgment, was an excellent procedure, but it has a serious defect. No such records can be introduced in court, for the reason that records of property transfers are often falsified as to values by the parties engaged in the transfer. However, such data form an excellent guide to the judgment of the experts engaged in determining land values, particularly where the opinions of people differ widely as to such values.

Having ascertained the value of lands adjacent to the railways, the next step is to multiply these values by some factor to arrive at the value of land for "railway purposes." Mr. Morgan says, in his report:

"The purchase of lands for a railroad right-of-way requires the consideration of two elements: First, the fair value of the land taken, and, second, the damage to the residue in consequence of a part of the tract having been taken for railroad purposes. The element of damage is dependent upon a variety of conditions, several of which may be mentioned as, the location and direction of the proposed railroad with respect to the boundaries of the property; the inconveniences and dangers likely to be suffered and attributable to the construction and operation of the line, such as the separation of the owner's house from his barn, or of his barn from his well.

The influence of public opinion for or against the construction of a line of railway is a most potent factor in respect of cost. [If one railway already exists, a projected second railway nearby will have to pay much higher prices for land, due to the fact that land owners do not feel the necessity of a second road and will "hold up" the new railway for the highest possible prices.—Editor.] In varying degrees, these and other considerations make the lands purchased for a railway right-of-way usually more costly than the true or normal value of lands for other purposes."

Mr. Morgan goes on to say that his agents had examined the bona fide sales of lands to railway companies, covering the more recently constructed lines, involving 7,000 acres and an expenditure of $4,200,000 in acquiring them in various parts of the state. As a result of this investigation and of a study of the whole subject, the conclusion was reached that a multiple of 3 should be used in converting the normal value of right-of-way lands to the "value for railway purposes." This multiple of 3 was not applicable to lands in the large terminals. St. Paul, Minneapolis and Duluth.

Mr. Morgan calls attention to an illuminating instance of the high cost of land acquired by condemnation as compared with the cost of land purchased by agreement. On the Illinois Central, in the counties of Mower and Freeborn, about 35% of the right-of-way was secured by condemnation proceedings and the company paid 4½ times the normal value of the land. The remaining 65% purchased by agreement cost only 1.7 times the normal value of the land.

The multiples used in arriving at the values of terminal property for railway purposes were as follows: For St. Paul, 1.75; for Minneapolis, 1.60; for Duluth, 1.25. In other words, the normal value of the bare land (not including buildings) in St. Paul was multiplied by 1.75 to obtain the "value for railway purposes." These multiples were arrived at as follows: Investigations made (in 1906) by a special tax committee of the city council of St. Paul had shown that property was assessed at about 60% of its selling price. Hence the assessed value of property adjacent to the terminals in St. Paul was divided by 0.6 (or multiplied by 1.66) to arrive at its normal value. This normal value was then multiplied by 1.75 to arrive at its "value for railway purposes."

The multiples of 1.75 for St. Paul, 1.60 for Minneapolis and 1.25 for Duluth were based upon the purchases of real estate by railways in those cities during the preceding six years. During that period more than 320 acres of property had been purchased by railways for about $3,000,000, Comparing the prices thus paid by railways with the prices paid by other corporations and individuals during the same period, the multiples above given were arrived at. Fortunately two railway companies had purchased land for terminals in St. Paul and one in Duluth during this six-year period, so that sufficient data were available to enable Mr. Morgan to arrive at a fair decision as to the multiples to be used.

An inspection of the physical property of the railway was made, practically all this inspection being done in a manner that will be

regarded as rather superficial by many of our readers. Each railway company provided a special train which carried the inspectors. "The train was moved at a low rate of speed so that observation could be had of the character and standards of construction and maintenance. Stops were made every mile, in places, but usually every two miles, and sometimes every five miles, to enable measurements of the roadbed and ballast, to observe the brand, weight and age of the rails and fastenings, to ascertain the average number of ties per mile by test measurements and counts; in fact, to make complete record of all the physical elements at these given points. Additional stops were frequently made at bridges and culverts for the purpose of measurement and inspection, and at all stations measurements of buildings were made, the inventories checked and notes made of any important changes.

"The detailed reports of the railway companies having been compiled on the forms prepared for that purpose, were in such systematic order by subjects as enabled the ready checking of the various items enumerated. The profiles were continually made use of to determine their accuracy. * * * Also as to whether sand, gravel, loose or solid rock cuttings, which would later serve as a guide in the classification of material in making the compilations and estimates of quantities in the office."

That this inspection was cursory is shown from the fact that about 100 miles of line were inspected each day of 10 hours from each train.

No inspection of rolling stock was made, as in the Wisconsin appraisal above referred to; but the "equipment reports were checked by the serial numbers of locomotives and cars."

The inspection was begun early in May, 1907, and continued almost without interruption until the middle of December, 1907, completing this feature of the work, "except the range roads, which were examined in the early part of 1908."

The unit prices assumed for estimating costs "are the results of much research." The unit prices submitted by the railways in their reports differed widely, and often in a manner not susceptible of explanation. For example, the price of steel rails varied from $20 to $31.50 per ton f. o. b. St. Paul; bridge steel of the same class ranged from 2½ to 4½ cts. per lb.; locomotives of the same type and weight varied from 6¾ to 12¾ cts. per lb.; engineering, superintendence and legal expense, between 1½ and 15%; interest during construction, 1 to 12%; contingencies, 5 to 50%.

Mr. Morgan selected unit prices to fit the local conditions and did not assume invariable unit prices for all roads, as was done in the Wisconsin appraisal.

"Adaptation and solidification of roadbed," or "seasoning of the roadbed," was regarded by Mr. Morgan "as a labor account covering a period of years," and treated as a separate item of cost, although it never appears in the records of any railroad company as a part of the cost of construction. According to the allowance made by Mr. Morgan, this item of "adaptation and solidification of road-

bed" amounted to $11,743,000 for the 7,596 miles of railways in Minnesota, or $1,545 per mile, or nearly 3% of the grand total cost of construction and equipment.

There is no doubt that the roadbed of a newly built railway requires more labor to maintain and that the cost of running trains of the roadbed is more expensive than after the embankments have settled and land slides and slips have become less frequent; but no two engineers will agree as to what allowance, if any, should be made for the cost of "seasoning." The fact is that much of this "seasoning" is due the action of rain, and casts nothing. Practically all the rest of it is done by the trackmen who are maintaining the track, as a part of operating expenses. The 7,600 miles of railways in Minnesota averaged 23,140 cu. yds. of earth, loose rock and solid rock. Hence, according to Mr. Morgan's estimate of $1,545 per mile for "seasoning," it would have cost nearly 7 cts. per cu. yd. for "seasoning" alone. Since earth can be spread and rolled for only a fraction of this 7 cts. per cu. yd., it is evident that most of this $1,545 item of "seasoning" must be due to some other class of work than grading. In giving his reasons for his seemingly large allowance for "adaptation and solidification of roadbed," Mr. Morgan says:

"The newly made excavations wash and slip, the ditches fill from the action of the elements, the embankments settle and the track superstructure is in almost constant need of attention; resurfacing, lining and dressing of ballasted and unballasted track is necessary, waterways become clogged up, bridges settle or go out of line, station grounds are to be improved and finished, scattered and unused material must be picked up and stored; in fact, all the loose ends which are the immediate sequence of construction must be gathered in and the property brought to an orderly condition."

While engineers will never agree as to the exact amount that should be allowed for "seasoning" of roadbed, still the majority would probably favor some allowance in estimating the cost of reproduction of an existing railway.

On the other hand, there will not be so many engineers who will favor any allowance for "contingencies" in estimating the cost of an existing railroad line. Mr. Morgan favors a small allowance for contingencies, and, as will be seen below, selected 5% as a fair estimate for this item, instead of the customary 10% used on estimates of projected lines. He says:

"Considering the detail with which the estimates have been prepared and the inclusion in them of many items of a contingent nature, it does not appear justifiable to consider an estimate of the cost of reproducing a railway as synonymous with an estimate for constructing a projected line. The essential difference rests in the fact that in reproduction cost the estimate is prepared in the light of known conditions, whereas for a projected line the contingencies are wholly unknown. These facts have been instrumental in reaching a determination that 5% for contingencies is fair under the circumstances attaching to the work of this appraisal."

In estimating the item of "interest during construction," Mr. Morgan assumed a rate of interest of 4% per annum on the money tied up during construction. "This rate of interest was applied to the total estimated cost of reproduction, assuming that the necessary funds would be fully employed one-half of the estimated time required to build the respective lines, which according to their mileage varied from 1 to 8 years." It will be seen from the data given below that this interest item amounted to about 8.8% of the total cost of reproduction as estimated for all the railways of the state.

The "present value" of each item was arrived at by deducting an estimated percentage of depreciation from the estimated "cost of reproduction." This estimated percentage of depreciation was furnished by hardly any of the railway companies, for they held that no real depreciation had occurred, and that a road is more valuable as a working tool years after its construction than when new. Mr. Morgan made his own estimates of depreciation, based upon the inspection above referred to, and thus arrived at the "present value" given below. It will be noted that the total "present value" is about 13% less than the "cost of reproduction."

Mr. Morgan did not secure the original cost of construction and betterments, and he states that such data were so incomplete as to render the task hopeless. He says that "for the older and more important railways, representing the greater part of the mileage of the state, the data for some of them is not available at all, and for others it is so incomplete as to render its development for practical use an impossibility."

We believe that Mr. Morgan is wrong in this conclusion, for in making the appraisal of the railways of Washington these same arguments were used by the railways, and it was only after a bitter struggle in some cases that access to all their records was secured which developed that practically all the costs of construction and betterments could be found, even for the lines built forty years ago. Among these Washington lines was the Great Northern, which has nearly 30% of the mileage in Minnesota. Its original records of cost (in the St. Paul office) are exceptionally well kept and complete, as well as its records of betterment costs. If only used as a guide in estimating the cost of reproduction, these original records (both in the accounting department and in the engineering department are practically invaluable. Furthermore, they are of great value in cases of litigation between the railway commission and the railway company where the accuracy of estimates of cost of reproduction are brought into question.

Another point of great importance is the percentages allowed for contingencies, for interest during construction and for engineering. Mr. Morgan has allowed 5% for contingencies, nearly 9% for interest during construction, and 4½% for engineering, superintendence and legal expense. Each of these percentages alone sounds small, but they aggregate more than $61,000,000 in Mr. Morgan's estimate. So enormous is this sum that the correctness of these

percentage allowances becomes a very important matter to the railway companies and to the state. We know of no satisfactory way of determining the correctness of these percentages except by ascertaining from the accounting records of the railways what their expenditures for such items actually have been. A thorough analysis of the accounting records would probably eliminate all of the item of "contingencies," amounting to $17,869,000 in the estimate for Minnesota, for any allowance for "contingencies" is always a confession of ignorance as to what the exact expenditure will be or has been. On the other hand, an analysis of accounting records might disclose that the percentages allowed for interest during construction and for engineering are too low, as claimed by many of the railways. We do not say that such would be the result, but so long as the claim is made and so long as such enormous sums of money are at stake, an analysis of the accounting records of every railroad should be made, even though the records may be incomplete for some of the older lines. It does not cost more than $6 or $7 per mile of road to make such an investigation and analysis of costs of original construction and betterments. Mr. Morgan informs us that his appraisal cost the state of Minnesota $8.50 per mile of main track, but of course, this does not include what it cost the railways to make the estimates which Mr. Morgan's forces checked, nor, as we have stated, did Mr. Morgan make an investigation and analysis of the original cost and betterments. The state of Minnesota has secured an exceedingly valuable estimate at a very low cost, but we can not urge too strongly the desirability of a thorough investigation of the accounting records of the railways and the subsequent use of accounting records in keeping cost estimates up to date.

We pass now to a summary of the data collected by Mr. Morgan:

Mileage in Minnesota.

(June 30, 1907)

	Miles.
Roadway, or 1st main track	7,596
Other main tracks	428
Side tracks	2,414
All tracks, total	10,438

From this it will be seen that there are 1.38 miles of tracks to each mile of roadway. Hence, the subsequent items of cost per mile of roadway must be divided by 1.38 to get the cost per mile of track.

TABLE XXIII.—COST OF REPRODUCTION AND PRESENT VALUE (7,596 MILES OF ROADWAY.)

	Cost of Reproduction New.	Present Value.
1. Land for right of way, yards and terminals	$ 73,201,757.70	$ 73,201,757.70
2. Grading, clearing and grubbing	56,006,782.11	56,006,782.11
3. Protect. work, rip rap, ret. walls	2,419,292.42	2,419,292.42
4. Tunnels	253,250.00	253,250.00
5. Crossties and switch ties	17,491,500.06	9,627,539.85
6. Ballast	9,413,351.34	9,413,351.34
7. Rails	33,010,087.72	25,199,668.20
8. Track fastenings	5,936,740.60	4,543,054.70
9. Switches, frogs, r. r. crossings	1,389,363.52	962,741.45
10. Track laying and surfacing	5,340,689.05	5,340,689.05
11. Bridges, trestles and culverts	19,567,524.80	14,518,834.30
12. Track and bridge tools	201,918.21	151,438.71
13. Fences, cattle guards, signs	2,768,394.93	1,403,082.54
14. Stockyards and appurtenances	559,896.21	349,759.71
15. Water stations	1,606,164.62	1,144,535.43
16. Coal stations	717,519.88	507,703.49
17. Station buildings and fixtures	5,855,258.56	4,097,249.08
18. Miscellaneous buildings	4,344,684.37	3,403,171.52
19. Steam and electric power plants, gas plants	797,484.52	656,069.99
20. General repair shops	4,123,119.91	2,959,019.07
21. Shop machinery and tools	1,831,671.22	1,484,756.11
22. Engine houses, turntables and cinder pits	2,837,988.58	1,874,436.40
23. Track scales	184,130.00	129,474.45
24. Docks and wharves (incl. coal and ore docks)	6,065,496.69	5,392,960.85
25. Interlocking plants	403,071.57	293,197.56
26. Signal apparatus	155,766.71	126,217.89
27. Telegraph lines, appurtenances	1,316,048.16	994,227.19
28. Telephone lines, appurtenances	94,526.17	70,926.17
29. Adapt. and solid. of road bed	11,743,007.15	11,743,007.15
Total of items 1 to 29 inclusive	$269,636,486.78	$238,230,206.93
30. Engineering, superintendence, legal expense, 4½%	12,133,641.89	12,133,641.89
Total of items 1 to 30 inclusive	$281,770,128.67	$250,363,848.82
31. Locomotives	17,090,953.40	12,608,422.67
32. Passenger equipment	6,616,170.78	4,554,442.63
33. Freight car equipment	46,911,106.58	34,068,095.26
34. Miscellaneous equipment	1,326,666.16	876,057.17
35. Marine equipment	43,500.00	32,625.00
Total of items 1 to 35 inclusive	$353,758,525.59	$302,503,491.55
36. Freight on crossties, rails, fastenings, switches and frogs	3,635,535.03	3,635,535.03
Total of items 1 to 36 inclusive	$357,394,060.62	$306,139,026.58
37. Contingencies, 5% on total of items 1 to 36	17,869,703.02	17,869,703.02
38. Stores and supplies	5,210,010.98	5,210,010.98
39. Interest during construction	31,261,419.93	31,261,419.93
Grand total	$411,735,194.55	$360,480,160.51

In Table XXIII it will be noted that the cost of reproduction and the present value of item 36 (freight on track materials) are identical; but since freight is a part of the cost of these materials delivered, and since the materials depreciate, the present value of item 36 should be less than the cost of reproduction. The error in this case arises from the segregation of freight as a separate item, which should not be done.

Item 37 (contingencies) is a percentage of all the previous items. It is not clear why contingencies should be figured on lands, nor on equipment.

By dividing each of the above items of cost of reproduction by 7,596, we have calculated the itemized cost of reproduction per mile of railway, tabulated below. To convert any of these items into cost per mile of track, divide it by 1.38, as above explained:

COST OF REPRODUCTION PER MILE OF ROADWAY. (7,596 MILES.)

1. Land for right of way, yards & terminals..	$ 9,637.00
2. Grading, clearing and grubbing..........	7,373.00
3. Protection work, rip rap, retaining walls.	318.00
4. Tunnels	33.00
5. Cross ties and switch ties...............	2,302.00
6. Ballast	1,240.00
7. Rails	4,345.00
8. Track fastenings	782.00
9. Switches, frogs and railroad crossings....	183.00
10. Track laying and surfacing..............	703.00
11. Bridges, trestles and culverts............	2,576.00
12. Track and bridge tools..................	27.00
13. Fences, cattle guards and signs..........	364.00
14. Stock yards and appurtenances..........	74.00
15. Water stations..........................	211
16. Coal stations...........................	95
17. Station buildings and fixtures.............	772
18. Miscellaneous buildings..................	572
19. Steam and electric power plants, gas plants..	105
20. General repair shops....................	543
21. Shop machinery and tools................	241
22. Engine houses, turntables and cinder pits....	373
23. Track scales............................	24
24. Docks and wharves (inc. coal and ore docks)	779
25. Interlocking plants......................	53
26. Signal apparatus........................	20
27. Telegraph lines and appurtenances.........	173
28. Telephone lines and appurtenances.........	13
29. Adaptation and solidification of roadbed....	1,546
30. Engineering, superintendence and legal exp.	1,598
Total of items 1 to 30 inclusive..............	$37,095
31. Locomotives	2,250
32. Passenger equipment....................	872
33. Freight car equipment...................	6,175
34. Miscellaneous equipment.................	175
35. Marine equipment.......................	6
36. Freight on cross ties, rails, switches and frogs, track fastenings.................	478
37. Contingencies	2,352
38. Stores and supplies in Minnesota..........	686
39. Interest during construction...............	4,115
Grand total................................	$54,204

The details of item 1 (land) are as follows per mile of roadbed:

	Per mile.
12.636 acres right of way	$1,217.90
0.620 acres gravel pits, etc.	33.32
2.973 acres station grounds	1,538.28
0.638 acres terminals (St. Paul, Minneapolis and Duluth)	6,846.84
16.866 acres, total	$9,636.34

These values are not the "normal values" of the land for ordinary purposes, but the "values for railway purposes" as ascertained by applying the multiples above given.

The most significant fact in this land appraisal is the very high percentage that the land for terminals forms. Station grounds also form a large percentage of the total cost for lands. There are many states in which such expensive terminals do not exist, and there are others, like Illinois, Pennsylvania and New York, where the cost of terminals is probably greater per mile of railway.

The details of item 2 (grading, etc.) are as follows per mile of roadway:

22,230 cu. yds. earth at 28.7 cts.	$6,380.01
565 cu. yds., loose rock at 51.62 cts.	291.65
345 cu. yds. solid rock at $1.077	371.57
4.56 acres clearing and grubbing at $69.85	318.52
Total	$7,371.75
Grade revision at Owatonna ($27,625)	3.63
Total	$7,375.38

Mr. Morgan's report contains no further data as to unit costs.

The itemized costs of each of the different railways in Minnesota are given in the report, and it was from a summary of those items that the above given totals and averages were prepared.

We append Table XXIV prepared by the Railway Age Gazette from the data contained in Mr. Morgan's report.

Appraising the Land Value of the Michigan Railways.*—The two letters that follow speak for themselves, and contain matter of interest not only to engineers who are likely to be engaged in railway appraisals but to engineers who may be called upon to appraise real estate and other property for taxation purposes.

H. P. Gillette,

Dear Sir:

In connection with some of your statements relative to the appraisal of the Michigan State Railroads made some years ago, you discuss admirably the element of real estate values and the methods which you think best to follow.

I gather that you are not quite as familiar with the methods finally employed in this work, because they were so in keeping with your own ideas and even went them one better that it is a pleasure for me to call it to your attention, knowing that you are highly appreciative of original work of this kind, and will be pleased to see that this particular expert's ideas and methods follow your

**Engineering-Contracting*, May 5, 1909.

TABLE XXIV.—MILEAGE, CAPITALIZATION AND VALUATION OF MINNESOTA RAILWAYS.

RAILWAYS	Mileage in Minnesota.	Minnesota Share of capital stock and funded debt.	Railways' estimate cost reproduction 1906	Commission's Estimates. "A" Cost reproduction, 1907.	"A" Present value, '07.	"B" Cost reproduction, 1907.	"B" Present value, '07.	Capital per mile in Minn.	Est. cost reproduction per mile. Railway's, 1906.	Com's estimate "A" 1907.
Chi., Burlington & Quincy	23.5	$ 757,242	$ 2,957,221	$ 2,726,670	$ 2,405,988	$ 2,451,931	$ 2,131,250	$32,278	$ 126,054	$ 116,226
Chicago Great Western	118	16,743,875	17,639,880	7,769,914	6,714,147	6,595,116	5,539,349	142,392	150,012	66,076
Chicago, Milwaukee & St. Paul	1,202	43,371,044	54,888,175	54,591,393	47,459,752	46,459,470	39,327,829	36,083	45,665	45,418
Chicago & North Western	651	25,068,954	20,914,139	21,214,978	17,463,934	18,154,144	14,790,100	38,492	32,113	32,574
Chicago, Rock Island & Pacific	236	12,095,605	11,280,105	8,716,215	7,779,600	7,493,711	6,577,096	51,207	47,755	36,900
Chicago, St. Paul & Minn., Oma.	431	16,717,540	29,217,691	26,778,560	22,838,120	22,553,406	18,612,966	38,777	67,772	62,113
Duluth & Iron Range	241	14,232,000	27,267,140	20,564,552	17,771,796	19,226,745	16,433,990	59,095	113,221	85,390
Duluth, Missabe & Northern	142	13,155,500	24,031,984	23,087,672	20,909,116	22,328,569	20,150,013	92,565	169,096	162,452
Duluth & North Eastern	63	500,000	665,582	859,865	711,737	791,496	643,368	7,874	10,481	13,541
Duluth & Northern Minnesota	35	200,000	968,039	880,008	675,956	836,477	632,425	5,714	27,658	25,143
Great Northern	2,050	78,268,492	134,823,938	107,074,102	94,415,343	95,406,976	82,748,216	38,181	65,770	52,233
Mason City & Ft. Dodge	27	3,237,425	1,625,205	772,072	622,941	690,926	541,795	118,587	59,531	28,281
Minn. & International	174	2,645,000	4,944,057	3,966,309	3,409,461	3,709,605	3,152,757	15,160	28,338	22,733
Soo	540	18,255,913	20,992,511	21,990,682	19,575,254	19,392,305	16,976,876	33,834	38,906	40,756
Minneapolis & St. Louis	378	20,884,937	21,845,196	16,622,245	14,276,189	14,185,150	11,839,093	55,184	57,721	43,921
Northern Pacific	967	55,898,480	86,817,468	69,397,955	61,099,563	60,679,409	52,381,010	57,801	89,772	71,760
Wisconsin Central	24	1,235,380	4,238,241	2,780,323	2,455,906	2,201,481	1,877,064	52,389	179,586	117,810
West. Minn. & Pacific	244	10,539,656	11,959,545	6,561,652	5,645,689	5,763,945	4,847,982	43,190	49,008	26,889
Illinois Central	30	1,172,648	819,544	944,302	800,845	798,458	655,001	38,868	27,164	31,300
Duluth, Un. Depot & Ter	0.4	....	1,018,170	910,698	817,541	821,545	728,388	....	2,558,217	2,888,135
Minneapolis Eastern	0.9	....	969,164	987,460	847,488	639,268	589,296	....	1,023,404	947,688
Minneapolis Union	3	....	7,773,750	4,321,250	4,021,728	3,364,425	3,064,904	....	2,955,798	1,643,061
Minneapolis Western	2	....	1,745,899	1,078,831	966,210	849,883	737,262	....	1,033,076	638,362
St. Paul Union Depot	0.6	....	5,495,150	4,354,202	4,184,311	2,847,343	2,677,453	....	9,812,767	7,775,360
Minnesota Transfer	12	....	5,777,987	2,873,283	2,591,546	2,332,762	2,051,025	....	462,239	229,863
Total	7,587	....	500,675,781	411,735,195	360,480,161	360,951,548	322,565,107	....	....	....

NOTE.—Average capitalization of railways in Minnesota (except the six switching roads, last mentioned in table), $44,206 per mile; average cost of reproduction of 19 carrying roads, as estimated by themselves, 1906, $65,909 per mile; Commission's estimate "A" cost of reproduction of carrying roads, 1907, $52,430 per mile; Commission's estimate "A," present value, $45,799 per mile; Commission's estimate "B," cost of reproduction of carrying roads, 1907, $46,202 per mile; estimate "B," present value, $39,571 per mile; average valuation placed on six switching roads (last mentioned) by roads themselves, $1,216,152 per mile; Commission's estimate "A," cost of reproduction of switching roads, 1907, $770,933 per mile; estimate "A," present value, $717,160 per mile; Commission's estimate "B," cost of reproduction of switching roads, $579,718 per mile; estimate "B," present value, switching roads, $525,945 per mile. Estimate "A" differs from "B" in that the value of lands in estimate "A" are taken at their "value for railway purpose" whereas in the "B" estimate the "normal value" of the land is assumed.

own so very closely and yet are carried out with a little different method as to details; for precision of detail and speed of accomplishment was only possible to a very well defined and carefully considered method entirely and exclusively evolved by Mr. Edward A. Dunbar, a former West Pointer and expert engineer, and well acquainted with real estate matters himself in large enterprises.

For economy of costs and in the completeness of the returns I think it is unexcelled, and has never been approached by any other equally reliable method, except your own; but all of them are much the same and splendid in their discussion of a very difficult and what has heretofore been a vexatious problem to solve.

I hope sometime in the near future to have the great pleasure of meeting you personally, for we highly appreciate your method of thinking about a good many things.

There has been in all this property so much theoretical stuff injected into it that it is very wearisome to practical men, and it is a relief to find some one like yourself who has the courage and the earnestness of purpose and honesty of intention to say so.

Yours truly,

F. T. BARCROFT,

Director of Appraisal.

Detroit, Mich., April 26, 1909.

My Dear Mr. Barcroft.—In compliance with your request I submit herewith a statement of the method by which the land values of the Michigan Railroad Appraisal were deduced.

LAND VALUATION.

The limited time in which full results had to be made known precluded the general adoption of any of the usual methods of land valuation and for that reason the following method was adopted:

Determining the Quantity.—The office inspectors, as they were called, took direct from the maps and other data of the railroad company, and of the registers of deeds offices, all the information necessary to determine the area of the railroad land throughout the state. They subdivided the land, in taking it off by counties and also subdivided it so the right-of-way between stations showed separately from the right-of-way and additional land at stations, or at points where the density of population would enhance the values of land beyond that of farm land.

In the cities the land was all divided into small blocks, so that it might be estimated either by square feet or by the front foot, as might seem most expedient.

Determining the Quality.—As the land throughout the state is not uniform quality the railroads' lands were subdivided into 83 subdivisions—following county lines. And on the basis of its physical characteristics, it was also subdivided into six separate classes, viz.:

1st. Farm land.

2d. Barren land.

3d. Towns under 500 population.

4th. Towns under 3,000 population.

5th. Towns under 10,000 population.

6th. Towns over 10,000 population.

To determine the percentage on each railroad in each county of farm and waste land a representative was sent to each of the railway centers of the state. He interviewed roadmasters, assistant roadmasters, locomotive engineers and freight train conductors, as being men who knew every foot of the land over which the railroad passed and from them secured the information which enabled him to report on the percentage of waste land on each railroad by counties.

In the smaller cities and a few of the larger villages the quality of land was determined by our representative going over the land within the city, dividing it up according to the use to which the various sections were put, viz.:

Laborers' residence property.

Mechanics' residence property.

High class residence property.

Manufacturing property.

Second-class store property.

First-class store property.

He also got local experts to value each division, but this really falls under the next head which is:

Determining the Price.—The price of the land in the first five classes, except as next before noted, was determined by sending a letter of inquiry, enclosing a card for reply, to some five hundred representative citizens of the state, taking about six from each county and choosing these citizens from among land dealers, bankers, county surveyors and county treasurers. Each man selected was supposed to be peculiarly adapted as a judge of land values within his county and on the card enclosed was requested to give his estimate of the present value of an average acre of land in his county in each of the five classes.

This method it will be observed assumes that every acre of land of the same class, in a county, is equally valuable and that that value may fairly be taken to be the average price of the land of that class in that county. An average of the prices by classes as given on the cards for each county was therefore taken as the present valuation for the first four classes and partly for the fifth. For part of the fifth and all of the sixth, the price was determined in the usual manner by a board of experts; going over every foot of the property in question and valuing each piece separately; taking into consideration surrounding values, both from selling prices of adjoining land and assessment rolls.

Our method of accumulating this information was by means of a card index file, of which I enclose a sample card. One card was made for each county through which each railroad passed. It is evident therefore that by applying the average prices to the class quantities, determining as hereinbefore described, that each card would represent the total present market value of all the land belonging to the railroad in question in that particular county, and the sum of the values given on all the cards, for any given railroad (that is one card for each county) would equal the actual

present market value of all the land owned by that railroad in the State of Michigan and that the total of all the cards would equal the total present value of all the railroad lands in the State of Michigan.

The question arose in our minds at the outset whether in addressing five hundred strangers, nearly all of whom were busy men, we should get any considerable number of replies to our inquiry and if we did, whether they would not be mere off-hand guesses rather than thoughtful estimates. It is extremely gratifying to be able to say that out of five hundred cards sent out less than fifty have failed to respond. In only one case was the failure to comply with the request based upon the plea of no compensation, and of all the answers received there is scarcely one that does not bear either in itself, or in an accompanying letter, evidence of the most painstaking care. It was noticed in many instances that before making out his card the writer would correspond with from five to twelve different persons in his county, getting their views and then summarizing them on his card.

I do not believe that had we gone over every acre of the land in this state, with a board of inspection and valuation, at enormous expense, we would have arrived at any better result than we did by the inexpensive and expeditious method detailed above.

Yours very truly,

E. C. DUNBAR.

Cost of 1,100 Miles of the C., M & St. P. R. R. in South Dakota.* —In the "Spokane Rate Case" before the Interstate Commerce Commission, Mr. A. H. Hogeland, chief engineer of the Great Northern Railway, and Mr. W. L. Darling, chief engineer of the Northern Pacific Railway, presented itemized estimates of the cost of reproducing those two railway systems. Acting for the city of Spokane, Mr. Halbert P. Gillette offered testimony showing that the estimates of Mr. Hogeland and Mr. Darling were too high. Among the facts most strongly in dispute was the allowance to be made for transporting the contractors' men and supplies over the railway to and from the site of the work. Mr. Hogeland testified that 4½ cts. per cu. yd. should be added to the contract price of each yard of earth excavation to cover the added cost to the railway company for transportation. Mr. Darling testified that 3 cts. per cu. yd. would cover this item and Mr. Gillette testified that 1 ct. would be an excessive allowance. In substantiation of his estimate Mr. Gillette presented data of his own and estimates made by other engineers. Among the latter was an estimate of Mr. D. J. Whittemore, made while he was chief engineer of the Chicago, Milwaukee & St. Paul. Mr. Whittemore presented his testimony in 1898 in the "South Dakota Rate Case" under conditions that made it desirable for him to claim all he reasonably could claim on the cost of construction of his road. His estimate covered the original cost of 1,101 miles of main line and 86 miles of sidetracks in South Dakota, which is equivalent to 1.08 miles of main line and

**Engineering-Contracting*, July 24, 1907.

sidings to each mile of main line. The unit prices used by Mr. Whittemore were based upon those prevailing in 1879 to 1887, the years during which the road was built. He testified that there was practically no rock excavation, which accounts in part for the low unit price in the earthwork.

Believing that Mr. Whittemore's estimate is worthy of being placed permanently on record, we reproduce it herewith. In a subsequent issue we shall give Mr. Hogeland's and Mr. Darling's itemized estimates of the cost of the two great railroad systems of which they are chief engineers:

	Per mile of main line (1,101 miles).
11,300 cu. yds. embankment at 15.16 cts.	$ 1,713.10
4.55 cu. yds. riprap at $1.50	6.80
10,000 ft. B. M. timber in bridges and culverts at $30 per M.	300.00
425 lin. ft. piles in bridges at 35 cts.	148.75
Truss bridges at $4,437 each	31.05
¼ iron pipe culvert in place of wooden one (betterment) at $50	12.50
96.63 tons (gross) rails at $46.76	4,518.40
7,555 lbs. track spikes at 2½ cts.	188.90
380 pairs rail joint splices at $1	380.00
3,238 cross ties at 30 cts.	971.40
0.63 switches at $100	63.00
0.01 railroad crossings at $200	2.00
1.08 miles main and side track laid and surfaced at $450	486.00
0.24 miles track ballasted at $500	120.00
Moving track material from store depot to the front	140.00
0.92 miles fence at $1.40	128.80
29 panels (0.1 miles) snow fence at $2.10	60.90
260 ft. B. M. crossing plant (1.1 crossings per mile) at $20	5.20
1 cattle guard	10.00
Freight on track materials, ¾ ct. per ton mile	2,130.00
Freight on contractor's tools and supplies	7.50
Freight on contractor's teams	6.00
Freight on bridge and culvert material	99.00
Transportation of laborers, 6 men transported 500 miles to work at 2 cents per mile	60.00
0.23 station sign board, at $6.00	1.40
1.1 highway sign board, at $5.0	5.50
0.04 R. R. crossing sign board, at $6.00	.25
0.04 R. R. crossing stop board, at $6.00	.25
2 whistle posts, at $1.00	2.00
0.45 mile posts, at $1.00	.45
1 rail rest, at $1.00	1.00
Buildings	855.00
1 mile right-of-way and station grounds	128.00
Telegraph lines	64.80
Engineering, superintendence, legal and general office expense	300.00
Interest on the above items for ½ of two years at 6%	777.00
Track tools, ⅛ section at $138 per section	17.25
Station furniture, 1/12 station, at $78	6.50
Betterment to roadbed and bridges, estimated at 5% of above	687.00
Stores and supplies	300.00
Total (exclusive of equipment)	$14,725.70

Mr. Whittemore testified that the $140 per mile for distributing track material from the store yard was estimated thus:

2 engines and crews at $25 per day	$50.00
36 cars at 50 cents per day	18.00
1 caboose	2.00
Total	$70.00

He stated that one-half mile of track was laid per day, hence it cost two times $70, or $140 per mile, to distribute track materials from the material yard.

It will be noted that the cost of transporting men and supplies, as given by Mr. Whittemore, consisted of three items, namely:

Freight on contractor's tools and supplies	$ 7.50
Freight on contractor's teams	6.00
Transportation of laborers	60.00
Total per mile	$73.50

This is equivalent to 0.66 ct. per cu. yd. of earthwork, if charged entirely to the earthwork.

Prices Used in Estimating Cost of Railways in Texas.*—The Railroad Commission of Texas has appraised the value of roads recently constructed, using a schedule of unit prices which we reproduce herewith.

The railways were paying $1.50 to $1.75 per day of 10 hrs. for common laborers in 1906, and found labor very scarce at these wages.

The following unit prices were used in valuing the Trinity & Brazos Valley Ry., from Mexia to Houston, a distance of 165 miles:

	Price.
Right of way, per acre	$ 50.00
Depot grounds, per acre (minimum)	100.00
Reservoir grounds, per acre	25.00
Clearing and grubbing, per acre	25.00
Clearing and grubbing, per acre	50.00
Earth excavation, per cu. yd	0.15
Loose rock excavation, per cu. yd	0.40
Solid rock excavation, per cu. yd	0.75
Trestle timber, in place, per M	40.00
Trestle piling, in place, per lin. ft	0.40
Wood drain boxes, per M	35.00
Tile drains, 24 in., per lin. ft	3.00
Cattle guards, wooden surface	40.00
Fences, 4-wire, cedar posts (16 ft. apart) per mile of fence	160.00
Road crossings, per M	35.00
Ties, L. L. Y. pine (6" x 8" x 8')	0.70
Rails, 75 lb., per ton	35.00
Joints, including bolts, each	1.20
Spikes, 34 kegs per mile, per keg	5.25
Track laying and surfacing per mile	500.00
Car and engine hire during construction, per mi.	250.00
Sidings (60-lb. rail, 2,640 ties per mile), per lin. ft	1.15
Switch furniture, per set	135.00
Ballast, sand (about 2,500 cu. yds. per mile), per mile	750.00
Telegraph line (for 1 wire, construction only, materials furnished by Western Union), per mile	50.00
Passenger depots, small frame, per sq. ft	1.00
Platforms for ditto, per sq. ft	0.16
Cotton platforms, per sq. ft	0.18

*_Engineering-Contracting_, July 24, 1907.

Engineering and legal expense, 5 per cent of total cost of construction.

Interest during construction, 5 per cent of total cost of construction.

For comparative figures the reader is referred to Lavis' "Railroad Location, Surveys and Estimates," page 193 et. seq.

Itemized Cost of the Northern Pacific Railway System as Estimated by Its Chief Engineer.*—In this article we give an estimate prepared by Mr. W. L. Darling, chief engineer of the N. P. Ry., and introduced as part of his testimony in the "Spokane Rate Case" before the Interstate Commerce Commission a few months ago.

While many of the quantities were guessed at by Mr. Darling, and while no quantities at all are given for many items, but simply lump sum estimates, still these data are worthy of being recorded, if only to indicate the relative cost of different items. Engineering, for example, is estimated at 3 per cent of the total, and this percentage is undoubtedly not far from correct, although the actual amount estimated for engineering is unquestionably very liberal.

The reader should bear in mind that this estimate was prepared for the purpose of proving that the Northern Pacific Ry. is not earning an unreasonable amount of money, considering what the physical value of the property is today. The city of Spokane contends not only that it is discriminated against in the matter of transcontinental freight rates, but that the rates are in themselves too high, and yield an unreasonable profit to the railways. The Northern Pacific and Great Northern Rys. contend that their rates are reasonable and yield only a fair profit; and, in proof, they have submitted estimates of the cost of reproducing their entire systems as they stand today, using what they claim to be current unit prices. Regarding these unit prices, it is only fair to say, that the City of Spokane contends that they are, in nearly every instance, unreasonably high. Mr. Halbert P. Gillette, in behalf of the City of Spokane, testified that much lower unit prices are commonly paid by railways in the northwest. He also criticised the quantities in many instances, claiming that they were mere guesses, and not trustworthy. We shall not go into all the testimony that was offered by both sides in the controversy, further than to put on record an abstract of the testimony of Mr. W. L. Darling, chief engineer of the N. P., and Mr. Hogeland, chief engineer of the G. N.

The mileage of the N. P. is as follows:

	Miles.
Main line, single and second track	2,860.67
Branch lines, main and second track	3,014.24
Spurs, sidings and yard tracks	1,819.88
All tracks, total	7,694.79

Of this track only 112 miles is second track.

*Engineering-Contracting, Apr. 15, 1908.

Mr. Darling's estimate of the cost was presented in the following form:

Grading and track	$138,745.971
Grade revisions, 1897 to 1901	2,350,600
Turnouts	1,838,750
Permanent bridges	9,950,248
Temporary bridges	4,284,580
Culverts	3,091,000
Wooden bridges filled	4,518,600
Tunnels	3,921,421
Fencing	707,290
Snow fences	537,600
Telegraph	1,443,000
Water supply	1,971,200
Coaling stations	635,900
Wharfs and docks	1,725,000
Stock yards	152,857
Track scales	107,671
Cattle guards	57,195
Round houses, turntables, power houses, etc.	1,680,448
Shop buildings	2,091,650
Miscellaneous buildings	1,578,528
Warehouses	2,886,016
Headquarters building	756,600
Furniture	440,000
Passenger stations	1,102,304
Combination stations	1,408,960
Duluth Union depot	343,300
St. Paul Union depot	159,200
Interlocking	123,555
Block system	44,307
Mile posts and signs	129,584
Ash pits	79,067
Oil and sand houses	120,960
Shop tools and machinery	1,100,000
Kalama ferry and steamer	617,400
Lines in Manitoba	7,000,000
Joint work, Seattle	2,457,000
Total	$200,155,762
Engineering, 3%	6,004,673
Total	$206,160,435
Contingencies, 10%	20,616,043
Total	$226,776,478
Interest during construction—4% for 2½ yrs., 10%	22,677,648
Total	$249,454,126
Freight equipment	30,486,000
Passenger equipment	5,898,000
Power	16,480,200
Floating equipment	497,000
Grand total	$302,815,326

This does not include lands which were estimated to be worth as follows:

Right of way, not including large terminals	$ 31,889,587
Large terminals	75,000,501
N. P. interest in terminal companies	882,655
Coal properties	50,720,120
Total	$158,492,913
Grand total	461,308,239

This estimate of the value of lands was not made by Mr. Darling.

In estimating the cost of grading, Mr. Darling stated that an estimate of quantities was made in 1898, and was as follows:

	Total.	Per mile (4,419 mi.).
Clearing, acres	15,089	3.4
Grubbing, stations	21,124	4.8
Earth, cu. yds.	88,334,218	20,000
Loose rock, cu. yds.	7,258,532	1,640
Solid rock, cu. yds.	5,164,479	1,170
Riprap, cu. yds.	1,548,911	350

At that time there were 4,419 miles of main track and branches, plus 850 miles of siding and yard tracks, or a total of 5,269 miles of track. In the year 1907, however, there were 1.4605 times as many miles of track. Hence, it is reasonable to suppose that each of the above quantities is 1.46 times larger now than in 1898. But, in addition to this, Mr. Darling claimed that all embankments had been widened from an original 14 ft. to a present 18 ft., and he estimated that all the above quantities (except the clearing and grubbing) should be multiplied by 1.20 to allow for this increase in bank widening. This would make a total increase of $1.20 \times 1.4605 = 1.7526$. Accordingly, Mr. Darling increased the grading quantities by 75.26% and secured the following quantities, to which he affixed the following unit prices:

22,036 acres clearing at $80.00	$ 1,762,880
30,851 stations grubbing at $16.50	590,042
116,110,918 cu. yds. earth at $0.28	32,511,055
38,703,637 cu. yds. hardpan at $0.42	16,255,528
12,721,303 cu. yds. loose rock at $0.50	6,360,651
9,051,266 cu. yds. solid rock at $1.10	9,956,393
2,714,621 cu. yds. riprap at $2.00	5,429,242
Total grading, etc.	$72,865,791

It will be noted that the 1898 estimate of quantities showed the following classification:

	Per cent.
Earth	88
Loose rock	7
Solid rock	5

But Mr. Darling claimed that fully one-quarter of this earth (or 22% of the total excavation) must have been hardpan, hence his estimate of 38,703,637 cu. yds. of hardpan above given.

Mr. Gillette testified that this 22% allowance for hardpan was fully three times too high. He also testified that it was not at all probable that branch lines built and acquired since 1898 had required as heavy grading as the work done before that time, and

that, in any event, an estimate of increase in yardage would more properly be based upon the increase in the miles of railway "line" rather than in the increase in the miles of "track." The miles of "line" had only increased 33%, as compared with an increase of 46% in the track mileage. Mr. Gillette testified that while it was possible that bank widening had increased the original yardage 20%, he knew that no such increase had occurred in the 1,500 miles of line owned by the Northern Pacific in the state of Washington; but, even conceding that an increase in the widths of embankments had been made throughout the system, certainly no rock cuts had been widened, no hardpan dug, no loose rock excavated, and very little riprap widened. Practically all bank widening had been made by steam shovels working in gravel pits, and that it was not right, therefore to increase the original yardage of solid rock, loose rock and hardpan by 20% when practically no such work had been done.

Mr. Darling's unit prices of reproduction were arrived at as follows:

Clearing:	
Contract price per acre	$75.00
Transportation of men and tools	5.00
Total	$80.00
Grubbing:	
Contract price per station	$15.00
Transportation of men, etc.	1.50
Total	$16.50
Earth.	Per cu. yd.
Contract price, average haul 400 ft.	$0.22
Overhaul	0.03
Transportation of men, etc.	0.03
Total	$0.28
Hardpan and cement gravel:	
Contract price	$0.35
Overhaul	0.04
Transportation of men, etc.	0.03
Total	$0.42
Loose rock:	
Contract price	$0.42
Overhaul	0.04
Transportation of men, etc.	0.04
Total	$0.50
Solid rock:	
Contract price	$1.00
Overhaul	0.05
Transportation of men, etc.	0.05
Total	$1.10
Riprap:	
Contract price, per cu. yd.	$1.75
Extra haul and work	0.15
Transportation of men, etc.	0.10
Total	$2.00

As to the unit prices for grading, Mr. Gillette testified that all the contract prices were very liberal, and that the allowances for overhaul and transportation were fully three times too high. The unit prices for clearing were too high, because most of the clearing was light clearing, a great deal of it being sage brush. The unit price for riprap was excessive, except for hand placed riprap, and that ordinary riprap could be contracted for at $1.25 or less.

The cost of the track was estimated as follows by Mr. Darling:

Cost per mile of main track:

117 tons steel at St. Paul at $31	$3,627.00
7.3 tons angle bars at $34	249.66
0.75 tons bolts and nuts at $55	41.25
3.4 tons spikes at $42	143.48
7.5 tons tie plates at $44	330.00
135.95 tons handled in material, yard, at $1	135.95
1 extra switch, per mile	27.50
Contract price for laying track	357.50
Train service and rent of equipment used in hauling to the front	375.00
3,000 ties at $0.55	1,650.00
Transportation of ties, rails, etc. (steel hauled 1,000 miles and ties hauled 400 miles at 0.4 ct. per ton mile)	1,023.80
3,000 cu. yds. gravel ballast at $0.66	1,980.00
Total, per mile	$9,941.14

Cost per mile of branch lines:

97 tons steel at St. Paul at $31	$3,007.00
6.46 tons angle bars at $34.20	220.93
0.75 tons bolts at $55	41.25
3.4 tons spikes at $42.20	143.48
107.61 tons handled in material yard, at $1	107.61
1 extra switch	27.50
Contract price for track laying	375.50
Train service, hauling to the front	375.00
2,880 ties at $0.55	1,584.00
Transportation of steel and ties	891.24
1,500 cu. yds. ballast at $0.66	990.00
Total, per mile	$7,763.51

The ballast was estimated thus:

	Per cu. yd.
Contract price	$0.27
Repairs to steam shovels, etc.	0.03
Transportation 1½ tons, 60 miles at 0.4 ct. per ton mile	0.36
Total	$0.66

In testifying regarding these quantities and prices, Mr. Gillette states that the Northern Pacific was not fully tie plated even on its main line; that the contract price for track laying was excessive; that the allowance for train service was nearly three times what such service actually costs; that the price of ties was excessive; that the estimated price of the gravel ballast was at least 50% too high, and that the quantity of ballast per mile was fully 50% in excess of the actual quantity.

Mr. Darling estimated the cost of each turnout as follows:

Set of switch ties	$ 54.00
Switch stand	13.30
Connecting rod	1.65
Frog	33.00
Split switch	31.00
Rail braces	1.60
Switch lamp	5.00
Guard rails	8.80
Freight charges	14.40
Total	$162.75

For the weight of rail used, and considering the character of the average turnout, this estimate is high.

Mr. Darling estimated the cost of the tunnels on the system as follows:

3,390 lin. ft. tunnels under 700 ft. in length.

1,090 lin. ft. tunnels of 700 to 1,200 ft. each.

7,548 lin. ft. tunnels of 1,200 to 4,000 ft. each.

9,833 lin. ft. tunnels, very long tunnel.

The above are single track tunnels lined with concrete. Beside these there were 4,919 lin. ft. of single track tunnels lined with wood, and 1,656 lin. ft. of double track tunnel lined with concrete.

The cost of single tunnels per lineal foot was estimated as follows:

Concrete lining:	Per cu. yd.
Contract price	$ 9.00
1¼ bbls. cement	2.50
Freight	1.00
Total	$12.50

With concrete averaging 2 ft. in thickness, there would be 4.1 cu. yds. per lin. ft.; hence the cost of lining would be 4.1 × $12.50 = $51.25 per lin. ft. of tunnel.

The cost of short tunnels (up to 800 ft.) was estimated as follows per lin. ft.:

	Per lin. ft.
Contract price	$ 50.00
Add 10% for extra excavation to make room for lining	5.00
Concrete lining	51.25
False work	13.00
Total	$119.25

For similar tunnels lined with wood instead of concrete, the estimate was $24.75 per lin. ft. for wood lining plus $55 for excavation, making a total of practically $80.

For longer tunnels the item of lining remained the same, but the item of excavation was estimated as follows:

Length of tunnel:	Price per ft.
Up to 700 ft.	$50 plus 10% = $55.00
700 to 1,200 ft.	55 plus 10% = 60.50
1,200 to 4,000 ft.	75 plus 10% = 82.50
4,000 to 10,000 ft.	90 plus 10% = 99.00

The 10% is added to cover the cost of the extra excavation to make room for the lining, and to these prices must be added the cost of the lining itself.

Mr. Gillette testified that the unit prices for tunnel excavation were very liberal, and that the allowance for lining was excessive. The allowance for "falsework," he said, seemed to be in error by a misplaced decimal point, and would be nearer correct if it were $1.30, since it could refer to nothing but the materials used in the forms, centers, etc.

Mr. Darling's estimate of the cost of short double track tunnels was as follows per lin. ft.:

Contract price $50 plus 10%	$ 55.00
11.5 cu. yds. extra excavation at $3	34.50
5.2 cu. yds. concrete at $12.50	65.00
Falsework	13.00
Total	$167.50

Mr. Darling's estimate of bridges was not given in much detail, but was as follows:

Howe truss bridges	$ 694,580
Steel and combination bridges	9,950,248
359,000 lin. ft. trestles at $10	3,590,000
Trestles filled with earth	3,012,415
Total bridging	$17,247,243

Other items were estimated as follows:

4,575 miles fencing at $154.55	$ 707,290
Water supply	1,971,200
1,750,000 sq. ft. wharfs and docks at $0.70	1,725,000
Coaling stations	635,936
3,412,000 sq. ft. stock yards at 4.48 cts.	152,857
74 track scales at $1,456	107,671
3,464 cattle guards at $16.80	57,195
Roundhouses, turntables, power houses, etc.	1,680,448
Shop buildings	2,091,650
Warehouses	2,886,016
Headquarters building	756,600
Passenger stations	1,102,304
Combination stations	1,408,960
Interlocking plant	123,555
Mile posts and signs (5,785 miles at $22.40)	129,584
Ash pits	79,067
Oil and sand houses at $1.68 per sq. ft.	120,960
Block system	44,307
Miscellaneous buildings and piping	1,578,528
320 miles snow fences at $1,680	537,600

The above costs include freight on the materials, and, in nearly every instance, this freight was estimated at 12% of the unit price assumed; thus, oil and sand houses were estimated at $1.50 per sq. ft. plus 12% for freight, making a total of $1.68 per sq. ft.

The following unit prices for building were used by Mr. Darling, and do not include freight:

Frame roundhouses, per stall	$1,300.00
Brick roundhouses, per stall	2,100.00
Turntables, each	5,000.00
Brick shops (1-story) per sq. ft.	1.50
Brick shops (2-story) per sq. ft.	2.50
Frame shops (1-story) per sq. ft.	1.00
Frame warehouses, per sq. ft.	1.20
Brick warehouses, per sq. ft.	1.60
Frame passenger stations, per sq. ft.	1.50
Brick passenger stations, per sq. ft.	2.50
Frame combination stations (1-story) per sq. ft.	1.50
Frame combination stations (2-story) per sq. ft.	2.50
Oil and sand houses, per sq. ft.	1.50

Mr. Darling failed to give the number of square feet of each of these different kinds of buildings.

For purposes of comparison, Mr. Gillette rearranged the foregoing figures of cost, following the classification used by the Interstate Commerce Commission, and divided each item by 5,875 miles, which is the mileage of main line and branches on the Northern Pacific system. The following table gives the results of this calculation, showing the cost per mile of main line and branches, and the percentages:

	Per mile.	Per cent.
1. Engineering	$ 1,027	2.04
2. Grading	12,814	25.44
3. Tunnels	670	1.33
4. Bridges, trestles and culverts	3,722	7.38
5. Ties	2,719	5.40
6. Rails	4,850	9.63
7. Frogs and switches	342	0.68
8. Track fastenings	705	1.40
9. Track laying	1,128	2.24
10. Ballasting	1,776	3.53
11. Fencing	116	0.23
12. Crossings, cattle guards and signs	30	0.06
13. Interlocking and signal	25	0.05
14. Telegraph lines	247	0.49
15. Station buildings	1,138	2.26
16. Shops and roundhouses	675	1.34
17. Machinery and tools	186	0.37
18. Water stations	337	0.67
19. Fuel stations	111	0.22
20. Warehouses	488	0.97
21. Docks and wharves	292	0.50
22. Miscellaneous structures	403	0.80
23. Interest	3,860	7.66
24. Marine equipment	106	0.21
25. Contingencies	3,509	6.97
26. Freight equipment	5,202	10.32
27. Passenger equipment	1,002	1.97
28. Locomotives	2,804	5.57
29. Floating equipment	86	1.17
Total	$ 50,370	100.00
Total	295,916,693	
Right of way and station grounds	107,772,743	
Grand total	$403,689,436	

The above does not include lines in Manitoba, estimated to cost $7,000,000 to reproduce, nor the coal properties valued at $50,720,120.

It will be noted that the $50,370 per mile multiplied by the 5,874.91 miles does not give exactly the total of $295,916,693. This is due to the fact that a slide rule was used in computing the cost of each item per mile, and absolute precision was not obtained. However, the error is only $4 per mile.

The reader should also note that the above costs per mile are not costs per mile of track, but per mile of all main and branch lines. Since there are 7,694.79 miles of all track, and only 5,874.91 miles of main and branches, there are 0.77 mile of main and branches for each 1.00 mile of "all tracks." Hence if we multiply any of the above 29 items by 0.77 we shall have the cost per mile of all tracks. Thus, item 9, Track Laying, is $1,128, which is the cost per mile of main line and branches, sidings and yards being lumped in. But the estimated cost of laying each mile of every kind of track is 0.77 × $1,128 = $868.

In our issue of June 22, 1907, are given estimates of the cost of all the railways in Wisconsin and Michigan. In a subsequent issue we shall give the estimated cost of the Great Northern Ry. system. A comparison of these various estimates should prove instructive to every engineer interested in railway construction.

Itemized Cost of the Great Northern Railway System as Estimated by Its Chief Engineer.*—In our issue of April 15 we gave an estimate of the cost of the Northern Pacific Railway similar to the one that will be given here. Both these estimates were presented as testimony before the Interstate Commerce Commission in their hearing of the "Spokane Rate Case." Since the object of the hearing was to ascertain the reasonableness of railway rates on the N. P. and on the G. N. railways, the railways naturally claimed a high physical value for their property. As stated in our April 15 issue, Mr. Halbert P. Gillette, testifying in behalf of the city of Spokane, claimed that the estimates presented by the railways were much too high, frequently being high not only as to unit prices but as to quantities.

Mr. A. H. Hogeland, Chief Engineer of the Great Northern Railway, presented the following as his estimate of the cost of reproducing the railway new at present prices.

The mileage of the Great Northern under operation April 1, 1907, was:

	Miles.
Main track	6,523.09
Second, 3d, 4th, 5th and 6th track	112.25
Side track	1,480.24
Grand total of all tracks	8,115.58

*Engineering-Contracting, May 6, 1908.

Mr. Hogeland's estimate of the cost was presented in the following summarized form:

1.	Engineering	$ 6,870,187
2.	Right of way and station grounds	87,067,532
3.	Grading	93,098,889
4.	Tunnels	7,447,620
5.	Bridges, trestles and culverts	17,953,028
6.	Ties	18,690,731
7.	Rails	31,054,392
8.	Track fastenings	7,375,495
9.	Frogs and switches	904,450
10.	Ballast	10,509,000
11.	Track laying and surfacing	6,998,409
12.	Fencing right of way	760,815
13.	Crossings, cattle guards and signs	1,922,160
14.	Interlocking or signal apparatus	386,190
15.	Telegraph lines	2,198,283
16.	Station buildings and fixtures	3,276,300
17.	Shops, roundhouses and turntables	3,667,900
18.	Shop machinery and tools	1,779,692
19.	Water stations	1,983,325
20.	Fuel stations	575,700
21.	Grain elevators	2,708,100
22.	Storage warehouses	276,500
23.	Docks and wharves	1,222,900
24.	Gas making plants	15,000
25.	Miscellaneous structures	3,194,850
26.	Track and bridge tools	142,877
27.	Stores and supplies on hand Feb. 28, 1907	5,395,463
28.	Contingencies	15,291,252
29.	Equipment:	
	Locomotives $10,756,324	
	Passenger cars 4,915,764	
	Frt. cars and other equip. 25,249,096	
		40,921,184
	Total	$373,688,224
30.	General and legal expenses (1%)	3,736,882
	Total	$377,425,106
31.	Interest during constr. (10%)	37,742,510
	Grand total	$415,167,616

Engineering was estimated at 3% of all items requiring engineering supervision, being all items except items 2, 26, 27, 29, 30 and 31.

Right of way and station grounds were estimated by the Right of Way Department.

The grading was estimated as follows:

27,018 acres clearing at $82.50	$ 2,228,985
340,000 sq. rods grubbing at $1.65	561,000
165,438,650 cubic yards earth at $0.31	51,285,982
33,973,350 cubic yards hardpan at $0.45	15,288,008
8,441,860 cubic yards loose rock at $0.55	4,643,023
12,771,060 cubic yards solid rock at $1.10	14,048,166
1,765,675 cubic yards riprap at $2.00	3,531,350
92,500 cubic yards retaining wall at $9.00	832,500
194,250 cubic yards slope wall at $3.50	679,875
Total grading	$93,098,889

Mr. Hogeland testified that the quantities of grading were arrived at as follows: "For 82% of the mileage of the system the actual quantities moved in construction were obtained from Engineering Department records. For the balance of the system the quantities could not be obtained in that way, because no records were available, and they were estimated from profiles and by comparison with adjacent portions of the system where the quantities were known. To these quantities were added the quantities moved since construction, in widening banks, reducing grades, taking out sags, filling bridges and widening and deepening cuts. The result being the actual quantities as nearly as possible to arrive at same, required to make the roadbed as it exists to-day."

It will be noted that Mr. Hogeland's estimate gives an average of 33,250 cu. yds. of excavation per mile of main track, distributed thus:

	Per cent.
Earth	75.0
Hardpan	15.4
Loose rock	3.8
Solid rock	5.8
Total	100.0

Mr. Hogeland testified that the part of the G. N. east of Havre (4,553 miles of main line) averaged 27,760 cu. yds. per mile, whereas the line west of Havre (2,082 miles of main line) averaged 45,250.

Mr. Hogeland gave the percentages as follows:

	East of Havre. Per cent.	West of Havre. Per cent.
Earth	88.4	57.0
Hardpan	10.2	22.4
Loose rock	1.1	7.4
Solid rock	0.3	13.2
Total	100.0	100.0

Mr. Gillette testified that Mr. Hogeland's estimate of yardage per mile was much too high, and cited actual records of the G. N. in the state of Washington where much of the heaviest grading on the G. N. is found. But, as we shall publish in detail Mr. Gillette's quantities and estimates of cost of each of the railway systems in the state of Washington, the reader may make comparisons for himself.

Mr. Hogeland arrived at his unit prices as follows:

Clearing:	Per acre.
Contract price	$75.00
Transporting men, tools and supplies	7.50
Total	$82.50

Grubbing:	Per sq. rod.
Contract price	$1.50
Transporting men, etc.	0.15
Total	$1.65

Earth:	Per cu. yd.
Contract price up to 1,000 ft. haul	$0.23
Overhaul	0.035
Transporting men, etc.	0.045
Total	$0.31

Hardpan:	Per cu. yd.
Contract price up to 1,000 ft.	$0.35
Overhaul	0.045
Transporting men, etc.	0.055
Total	$0.45

Loose rock:	Per cu. yd.
Contract price up to 1,000 ft.	$0.45
Overhaul	0.045
Transporting men, etc.	0.055
Total	$0.55

Solid rock:	Per cu. yd.
Contract price up to 1,000 ft.	$1.00
Overhaul	0.045
Transporting men, etc.	0.055
Total	$1.10

Riprap:	Per cu. yd.
Contract price	$1.50
Overhaul or train service	0.35
Transporting, etc.	0.15
Total	$2.00

Retaining wall:	Per cu. yd.
Contract price (concrete or rubble)	$7.50
Train service	0.80
Transporting men, etc.	0.70
Total	$9.00

Slope wall:	Per cu. yd.
Contract price	$2.50
Train service	0.75
Transporting men, etc.	0.25
Total	$3.50

It is interesting to note in this connection that the actual yardage of excavation on about 700 miles of the G. N. in the state of Washington was 26,000 cu. yds. per mile for the original construction in the early '90's, and that the item of "overhaul" actually averaged less than ½ ct. per cu. yd. for every yard of material excavated, as compared with the 4½ cts. estimated by Mr. Hogeland. The free haul limit was 1,000 ft. Much the same criticism also applies to Mr. Hogeland's estimate of the cost of transporting men and supplies to and from the site of the work.

Mr. Hogeland's estimate of tunnels was as follows:

5,232 lin. ft. unlined single track tunnel at $70	$ 366,240
17,346 lin. ft. timber lined single track tunnel at $120	2,081,520
6,139 lin. ft. concrete lined single track tunnel (Boulder) at $175	1,074,325
13,813 lin. ft. concrete lined single track tunnel (Cascade) at $195	2,693,535
5,141 lin. ft. concrete lined double track tunnel at Seattle, $1,848,000, two-thirds to G. N.	1,232,000
Total	$7,447,620

The unit prices were arrived at as follows:

Unlined tunnel:	Per lin. ft.
Contract price for standard unlined section	$55.00
Extra excavation	8.00
Transporting men, tools, supplies, etc.	7.00
Total	$70.00

Timber lined tunnel:	Per lin. ft.
Contract price for standard unlined section	$ 55.00
Enlargement for timber lining	30.00
Timber and iron in place	25.00
Transporting men, etc.	10.00
Total	$120.00

Concrete lined tunnels: Per lin. ft.

(BOULDER TUNNEL.)

Excavation	$ 90.00
Temporary timber lining	20.00
Permanent masonry lining	45.00
Transporting men, etc.	20.00
Total	$175.00

(CASCADE TUNNEL.)

	Per lin. ft.
Excavation	$ 95.00
Temporary timber lining	25.00
Permanent concrete lining	50.00
Transporting men, etc.	25.00
Total	$195.00

Bridges, trestles and culverts:	
1 stone arch (Minneapolis), 1,770 lin. ft.	$ 867,000
260 steel bridges with masonry piers, 63,557 lin. ft.	6,941,645
3,934 timber trestles, 429,851 lin. ft.	5,216,480
189 Howe truss spans, 19,996 lin. ft.	905,478
4,940 permanent culverts	3,021,685
4,021 timber culverts	1,000,740
Total	$17,953,028

Mr. Hogeland did not give the number of pounds of steel, yardage of masonry, etc. He stated, however, that he used the following unit prices, to which he subsequently added ½ ct. per ton per mile for transporting the materials, so that these unit prices do not include the cost of transporting the materials:

Steel in bridges:	Per ton.
Contract price ready to erect, f. o. b. St. Paul	$65.00
Mill and shop inspection	.75
Erection	12.00
Painting	2.25
Total	$80.00

This is equivalent to 4 cts. per lb. erected, exclusive of the cost of transportation from St. Paul.

Masonry:	Per cu. yd.
First class	$12.00
Second class	8.00
Concrete	6.00

Excavation, coffer dams, pumping, etc., variable.

Timber trestles:	
Timber in place, per M	$31.50
Piling in place, per ft	0.35
Wrought iron, per lb	0.05

Freight to be added.

Howe truss spans:	Per lin. ft.
44 ft	$18.50
60 ft	27.00
75 ft	34.00
87½ ft	35.50
100 ft	37.50
125 ft	42.00
150 ft	45.00

Freight to be added.

Howe truss timber, per M	$25.00
Rods, plates, etc	0.03
Bolts	0.025

Freight to be added.

Vitrified pipe culverts:	Per lin. ft.
12-in. pipe	$0.25
18-in. pipe	0.50
24-in. pipe	1.15
27-in. pipe	1.52

Freight to be added.

Cast iron pipe culverts, $30 per net ton, plus freight.

Mr. Hogeland estimated 2,850 ties per mile of main track and 2,750 per mile of side track, at the following cost:

Delivered on right of way	$0.48
Train service and loading and handling	0.09
Burnettizing ¼ of all ties at 16 cts	0.04
Transporting 500 mi. at ⅛ ct. ton mile	0.21
Total	$0.82

He estimated 8,880 sets of switch ties as follows per set:

F. o. b. mill, per M	$60.00
Transporting 500 miles, per M	15.00
Total	$75.00

The rails for the main track averaged 68.1 lbs. per yd. and for the side track 60 lbs. Five rails per mile were added for "repair rails." The cost of rails was estimated to be:

	Per gross ton.
F. o. b. St. Paul, including handling	$32.00
Transp. 800 miles at ½ ct. ton mile	4.00
Total	$36.00

Angle bars were estimated at 17,600 lbs. per mile of side track at a cost of:

	Per net ton.
F. o. b. St. Paul	$40.00
Transporting 800 miles	4.00
Total	$44.00

Bolts and nuts were estimated at 1,800 lbs. per mile of main track and 1,500 lbs. per mile of side track, at a cost of:

	Per net ton.
F. o. b. St. Paul	$54.00
Transporting 800 miles	4.00
Total	$58.00

Spikes were estimated at 6,500 lbs. per mile of track, at a cost of:

	Per net ton.
F. o. b. St. Paul	$42.00
Transporting 800 miles	4.00
Total	$46.00

Tie plates were estimated at 29,000 lbs. per mile of track where fully tie plated (or 5 lbs. per tie plate), and it was assumed that 2,451 miles were fully tie plated and 1,950 miles half tie plated, as a cost of:

	Per net ton.
F. o. b. St. Paul	$45.00
Transporting 800 miles	4.00
Total	$49.00

It was assumed that 750 miles of track were provided with rail braces at 2,000 braces per mile, at a cost of 10 cts. per brace.

Summary of track fastenings:

Angle bars	$3,090,736
Bolts and nuts	431,288
Spikes	1,304,284
Tie plates	2,399,187
Rail braces	150,000
Total	$7,375,495

Mr. Gillette testified that these items were substantially correct except as to the number of tie plates, which was very much over-estimated.

Frogs and switches:	
Complete turnout, f. o. b. St. Paul (3,750 lbs.)	$85.00
Transp. 800 mi. at ½ ct. ton mile	7.50
Total	$92.50
8,880 turnouts (except ties) at $92.50	$821,400
302 crossing frogs at $275	83,050
Total	$904,450

The "complete turnout" includes switch stand and bolts, lamp, switch points, connecting and tie rods, plates, rail braces, clips, frog and guard rail, but does not include cross ties.

Mr. Hogeland estimated that 3,750 miles of the main track averaged 3,000 cu. yds. of gravel ballast per mile, and that 1,900 miles averaged 2,250 cu. yds. per mile. Of the 1,480 miles of side track, he estimated that 950 miles were ballasted with 1,500 cu. yds. per mile. This made a grand total of 16,950,000 cu. yds. of ballast on the system, the cost of which was estimated as follows:

	Per cu. yd.
Loading, unloading, putting under track and dressing track	$0.27
Maintenance and repairs of steam shovels	0.05
Train service, hauling, repairs and rental of equipment, transp. of men, tools and supplies	0.30
Total	$0.62

Mr. Gillette testified that this estimate of unit cost was fully 50 per cent more than the actual cost as shown by the records of the G. N. and that gravel ballast could be placed for less than 40 cts. per cu. yd. under existing conditions.

Mr. Hogeland estimated the cost of track laying and surfacing as follows:

	Per mile.
Curving rails, laying and surfacing	$350.00
Labor of tie plating (average)	45.00
Train service and rental of equipment and hauling to front	390.00
Transporting men, supplies, etc.	50.00
Total	$835.00
8,115.58 miles at $835	$6,776,409
8,880 switches placed at $25	220,000
Total	$6,998,409

Mr. Gillette testified that the item of train service was about three times higher than the actual cost, and that the transportation of men, etc., was even more excessive.

Mr. Hogeland estimated 4,611 miles of right of way fences at the following cost per mile:

	Per mile.
Standard fence	$150.00
Train service distributing materials	10.00
Transporting men, etc	5.00
Total	$165.00

He estimated the cost of crossings, cattle guards and signs as follows:

6,635.34 miles of $75 for cattle guards, signs, etc.	$ 497,650
58 steel highway bridges (overhead)	1,344,000
Timber bridges (overhead)	80,510
Total	$1,922,160

Interlocking and signal apparatus:

Interlocking	$327,750
Block signaling	58,440
Total	$386,190

Telegraph lines:

Labor	$ 650,614.48
Material	1,295,207.46
Train service	16,638.00
Transp. men, tools, material, etc	219,598.22
Quadruplex instruments, batteries, furniture, etc., in 8 main offices	16,225.00
Total	$2,198,283.16

This is equivalent to the following cost per mile of telegraph line:

	Per mile.
Labor	$ 98.00
Material	200.00
Train service	2.50
Transporting men, etc	33.00
Quadruplex instruments, etc	2.50
Total	$336.00

Mr. Gillette testified that this was an excessive estimate, and that, so far as the state of Washington was concerned, the G. N. did not own a large part of the telegraph lines and that, in fact, it was the common practice for railways to share the ownership of the lines with telegraph companies, as shown by the accounting records of the railways:

Passenger depots:

Seattle (one-half interest)	$ 295,000
Spokane	137,500
Grand Forks	37,500
Fargo	41,800
Sioux City	180,000
Minneapolis union depot	342,500
29 other passenger depots of brick or stone	419,600
705 frame passenger and freight depots	1,226,700
14 freight depots of brick or stone	422,900
Frame freight houses	172,800
Total	$3,276,300

The St. Paul union depot (of which the G. N. owns one-ninth interest) and the Superior depot (of which the G. N. owns one-third interest) are not included above, but are included under "right of way and station grounds." Mr. Hogeland did not give any dimensions of buildings, so that it is impracticable to check his estimates.

Shops, roundhouses and turntables:

Shop, St. Paul	$ 854,400
Shop, St. Cloud	75,400
Shop, Superior	91,000
Shop, Barnesville	17,500
Shop, Sioux City	12,500
Shop, Devils Lake	60,000
Shop, Havre	91,000
Shop, Great Falls	42,000
Shop, Spokane	124,800
Shop, Everett	70,200
Roundhouses, frame, 88 stalls, at $1,400	123,200
Roundhouses, masonry, 554 stalls, at $2,100	1,163,400
Boiler houses, power houses and small shops	216,000
Turntables, frame, 10, at $1,800	18,000
Turntables, steel, 57, at $6,500	370,500
Cinder pits	140,000
Store houses, oil and sand houses and scrap bins	198,000
Total	$3,667,900

Water stations:

420 water stations (at $4,722)	$1,983,325

This includes tanks, pump houses, pumps, engines, wells, reservoirs and all appurtenances of water stations. It will be noted that this supplies one station every 16 miles of road.

Fuel stations:

52 standard coaling stations at $9,500	$ 544,500
52 platforms coaling stations, portion with cranes and buckets, $600	31,200
Total	$ 575,700

Grain elevators:

Minneapolis	$ 240,000
Superior, A and X	823,100
Superior S (steel)	1,536,400
Seattle, Smith's Cove	108,600
Total	$2,708,100

Storage warehouses:

Superior, flour shed	$ 142,800
Five wool houses	19,800
Seattle, warehouse, Smith's Cove	113,900
Total	$ 276,500

Docks and wharves (including dredging):

Superior No. 1	$ 175,000
Superior No. 2	80,800
Superior Nos. 5 and 6 and machinery	449,500
Seattle, Smith's Cove dock	517,600
Total	$1,222,900

Miscellaneous structures:

General office building, St. Paul	$ 590,000
Division office buildings	18,000
Boarding houses	87,500
Section houses, bunk houses, hand car houses	853,500
Ice houses	107,500
Stock yards	157,600
Track scales	92,250
Snow sheds	295,000
Snow fences	450,000
Loading platforms	71,000
Quarry and crusher plants	45,000
Tie treating plant	85,000
Commissary buildings	15,000
Miscellaneous buildings	327,500
Total	$3,194,850

Mr. Hogeland allowed 10 per cent of items 3, 4, 5, 10, 11, 16, 17, 19, 20, 21, 22, 23 and 25 for "contingencies," to cover the increased cost of the work due to unforseen causes, such as fires, floods, tornadoes, accidents, etc. Mr. Gillette testified that, while an allowance for "contingencies" is certainly permissible in estimating the cost of *projected* work, it is not permissible in estimating the cost of *completed* work, particularly where the actual costs are on record for nearly all the work, as is the case of the G. N.

In estimating the interest charges during construction, Mr. Hogeland assumed that the system, including equipment, would be unproductive for a period of two years. He assumed that it would take eight years to reproduce the system, 1,000 miles of track (main and side) being built per year, and that it would be two years after the beginning of the work before the first 1,000 miles would produce sufficient revenue to pay interest on the investment, and so on with the rest. Hence, two years at 5% is 10% of the total cost to be charged for interest.

It will be interesting to compare this estimate with the actual interest charges as taken from the ledgers of the different railway companies operating in the state of Washington. These data will be published in this journal in the near future, along with the other items of actual cost as ascertained by Mr. Gillette for the Railroad Commission of Washington.

For purposes of comparison with the estimated cost of the N. P. (published in our April 15 issue) we append the estimated cost of the G. N., by items per mile of main and second track, as determined by dividing Mr. Hogeland's items by 6,635.34.

The mileage of the Great Northern under operation April 1, 1907, was:

6,635.34	miles main and second tracks.
1,480.24	miles side tracks.
8,115.58	miles total tracks.

There are only 112.25 miles of second track included in the above, and it will be seen that there is 0.22 mile of side track per mile of main and second track.

	Cost of reproduction per mile of main and second track. (6,635.24 miles.)
1. Engineering	$ 1,035
2. Right of way and station grounds	13,160
3. Grading	14,030
4. Tunnels	1,070
5. Bridges, trestles and culverts	2,705
6. Ties	2,820
7. Rails	4,680
8. Track fastenings	1,110
9. Frogs and switches	135
10. Ballast	1,585
11. Track laying and surfacing	1,055
12. Fencing right of way	115
13. Crossings, cattle guards and signs	290
14. Interlocking and signal apparatus	60
15. Telegraph lines	330
16. Station buildings and fixtures	495
17. Shops, roundhouses and turntables	550
18. Shop machinery and tools	270
19. Water stations	300
20. Fuel stations	90
21. Grain elevators	420
22. Storage warehouses	40
23. Docks and wharves	185
24. Gas making plants	2
25. Miscellaneous structures	480
26. Track and bridge tools	20
27. Stores and supplies on hand	815
28. Contingencies	2,300
29. Equipment	6,170
30. General and legal expense	563
31. Interest	5,690
Grand total	$62,570
Deduct right of way and station grounds	13,160
Cost, exclu. of right of way and sta. grounds	$49,410
Deduct equipment	6,170
Cost, exclusive of lands and equipment	$43,240

Contract Prices for Railway Work in the State of Washington.*— In building the Chicago, Milwaukee & St. Paul line through the state of Washington, the contract prices for work let in 1906 were as follows:

	Average price per cu. yd.
Earth excavation, haul 300 ft. or less, $0.17 to $0.22	$0.19
Earth excavation, haul 300 to 1,000 ft., $0.21 to $0.27	0.23
Hard pan, haul 1,000 ft. or less, $0.30 to $0.43	0.37
Cement gravel, haul 1,000 ft. or less, $0.36 to $0.40	0.38
Loose rock, haul 1,000 ft. or less, $0.33 to $0.45	0.42
Solid rock, haul 1,000 ft. or less, $0.80 to $1.00	0.90
Riprap, loose, haul 1,000 ft. or less	0.75
Riprap, hand placed, haul 1,000 ft. or less	1.25
Overhaul, for each 100 ft. beyond 1,000 ft.	0.01

**Engineering-Contracting,* Dec. 15, 1909.

Other prices were as follows for different units:

Clearing, per acre, $40.00 to $300.00	$120.00
Grubbing, per station, $10.00 to $20.00	15.00
Ties made on right-of-way, each	0.18
Tunneling (800 ft. long or less), per lin. ft.	45.00
Tunnel enlargement, per cu. yd.	3.00
Tunnel timber in place, per M.	28.00
Log culverts, per lin. ft. of logs	0.14

The contract prices on the Portland and Seattle Ry., built in Washington at the same time as the C., M. & St. P., were as follows:

	Per cu. yd.
Earth excavation, haul 300 ft. or less	$0.17
Earth excavation, haul 300 to 1,000 ft.	0.21
Hardpan, haul 1,000 ft. or less	0.35
Loose rock, haul 1,000 ft. or less	0.40
Shell rock, haul 1,000 ft. or less	0.30
Solid rock, haul 1,000 ft. or less	0.90
Riprap, loose, haul 1,000 ft. or less	0.90
Riprap, hand placed, haul 1,000 ft. or less	1.25
Overhaul for each 100 ft. beyond 1,000 ft.	0.01

Other prices were as follows on different units:

Clearing, per acre	$ 25.00
Grubbing, per sq. rod	1.50
Wrought iron, spikes, etc., in structures, per lb.	0.05
Cast iron in structures, per lb.	0.05
Square timber in culverts, per M.	20.00
Flatted timber in culverts, per lin. ft.	0.12
Tunnel in rock (16 x 24 ft.), per lin. ft.	45.00
Tunnel, extra excavation, per cu. yd.	3.00
Tunnel timber lining, including iron, per M.	20.00
Piling, per lin. ft., cut off	0.10
Piling per lin. ft., driven	0.20
44-ft. Howe truss bridge, per lin. ft.	9.25
60-ft. Howe truss bridge, per lin. ft.	13.50
75 to 88-ft. Howe truss bridge, per lin. ft.	19.00
100-ft. Howe truss bridge, per lin. ft.	20.00
120 to 125-ft. Howe truss bridge, per lin. ft.	21.00
150-ft. Howe truss bridge, per lin. ft.	22.00
Concrete (cement furnished by the company), per cu. yd.	6.00
Concrete in tunnels (cement furnished by the company), per cu. yd.	7.00
Track laying, including loading all material, per mile	300.00
Switches placed, each	25.00
Placing tie plates, per mile, fully tie plated	75.00
Ballast (gravel), including track surfacing, per cu. yd.	0.27

The price for ballast does not include hauling it, which was done by the railway company. The prices for Howe truss bridges include all materials except the iron, and all framing and erecting.

Record of Rapid Construction on the C. P. Ry.—In the Jour. Assoc., 1884, p. 150, Mr. E. T. Abbott gives a brief account of the rapid construction of 500 miles of single track road across the prairies from Brandon (132 miles west of Winnipeg). Ground was broken May 28, 1882, and continued to Dec. 31. In 182 working days, including stormy ones, with a force of about 5,000 men and 1,700 teams, the contractors did the following:

6,104,000 cu. yds. earth excavation (or 14,000 cu. yds. per mile), 2,394 M. timber in bridges and culverts, 85,700 lin. ft. piling, and 435 miles of track-laying. The track was all laid from one end, and in no case were the rails hauled ahead by team. Two iron

cars were used, the empty one on its return being turned up beside the track to let the loaded one by. The tracklaying crew was equal to 4 miles a day. In the month of August, 92 miles of track were laid. The grading forces were scattered along 150 miles ahead of the track. Sidings 1,500 ft. long were graded 7 miles apart.

It will be noted that the grading force averaged 34,000 cu. yds. excavation, 13 M. timber, and 500 ft. piling, per day. Hence each horse, plus 1⅛ men, averaged 10 cu. yds. per day.

Weight and Cost of Steel in Brooklyn Elevated Railways.*—In 1896 there were about 20 miles of double track elevated railways in Brooklyn, and the average weight of steel was 6,780,000 lbs. per mile, or nearly 1,300 lbs. per lin. ft. This weight was about 20% in excess of what would have been necessary if the columns could have been placed in the roadway; but, due to the narrow streets, fully 4% of the columns were placed at the edge of the sidewalks, necessitating transverse girders 35 to 45 ft. long. The average length of the longitudinal girders was 50 ft. The following is typical of the distribution of the steel in more modern sections (built in 1893), which averaged 7,840,000 lbs. per mile, or nearly 1,500 lbs. per lin. ft., the transverse girders being 45 ft. long:

	Per cent.
Columns	11.5
Transverse girders	20.5
Longitudinal girders (two tracks)	57.0
Station platforms	5.0
Bracing	6.0
Total	100.0

This work cost nearly 3 cts. per lb. erected, at which rate the steel work cost nearly $45 per lin. ft., or less than $240,000 per mile. Ties 7 x 8 ins., spaced 15 ins. c. to c., were used; guard rails, 6 x 8 ins. The earlier lines were built with 60-lb. rails, but in 1893 rails weighing 85 lbs. were adopted. Stations average 1,800 ft. apart. The locomotives weighed 45,000 to 56,000 lbs., the wheel base being 16 ft.

Cost of the Early Elevated Railways in New York City.*—The cost of a mile of double track elevated railway on Manhattan Island, New York City, up to 1880, when there were 35 miles, is given by Mr. R. E. Johnston as follows:

Foundations, columns, superstr. and track	$288,400
Stations	60,000
5 locomotives at $4,000	20,000
12 cars at $3,300	39,600
Total	$408,000

The foundation pit is 7 ft. square and 7 ft. deep.

*Engineering-Contracting, Oct. 7, 1908.

The foundation of each column is of brick 4 x 4 ft. on top and 6 x 6 ft. at the base, 4 ft. high, resting on two 6-in. flagstones, 3 x 7 ft. each, which in turn rest on 4 ins. of concrete.

The cast-iron base of the column weighs 3,000 lbs. and is secured by four 2-in. bolts that pass through the foundation.

The longitudinal girders are 44 ft. long.

Nothing was paid for damage to property.

Labor Cost of Track Laying on Elevated Railways in New York City, Also Some Costs of Erecting Steel.*—The following costs relate to track-laying on elevated roads on Manhattan Island, and, although the work was done 28 years ago, the records are given by Mr. G. Thomas Hall in such detail as to be applicable to-day, provided proper substitutions are made for wages.

The Second Avenue line was double track, and about 7.4 miles long, of which about 2% was curved.

The contractors found the following organization the most effective for track-laying:

15 carpenters.
10 skilled laborers assisting carpenters on the guard timbers.
10 men laying steel rails.
10 men clipping cross-ties.
10 men spacing, marking and edging cross-ties.
10 unskilled laborers for derrick, distributing materials, etc.
2 horses with drivers.
3 foremen.

The clippers were kept 500 ft. ahead of the spikers, and the spikers 750 ft. ahead of the carpenters on the guard timbers. Horsepower was found to be cheaper than steam in hoisting track material from the street. The cross-ties were first hoisted, distributed and spaced; then marked for camber by means of T sights, adzed and clipped. Then the steel rails were in turn distributed, lined up and spiked; then the guard timbers were distributed, ends jointed, gaged and bolted down; the inside guard being put in place and finished with strap iron before the outside one was laid. A space of about 250 ft. intervened between the gangs employed on the two ranges of guard timbers. Everything working smoothly, the above force laid about 260 ft. of *double* track per 10-hr. day on tangent work.

The following was the cost to the contractor of laying complete 1,000 lin. ft. of straight *single* track:

Hoisting and distributing materials	$ 40.00
Laying cross-ties	65.00
Laying steel rails	30.00
Laying guard timbers	100.00
Strap ironing guard timbers	20.00
Incidentals, loss of time, repairing, tools, etc.	25.00
Superintendence	20.00
Total for 1,000 ft.	$300.00

The contract prices were 35 cts. to 43 cts. per lin. ft. of single, straight track.

**Engineering-Contracting*, June 2, 1909.

Wages of common laborers were 15 cts. per hr. The above crew of 70 men and 2 horses received about $145 a day, or practically 20 cts. per hr. per man.

The amount of materials in 1,000 ft. of single track was as follows:

250	cross-ties, 6" x 6" x 12', 9,000 ft. B. M.
500	cross-ties, 6" x 6" x 8', 12,000 ft. B. M.
3,000	wrought-iron clips, ½" x 2½" x 5½".
1,500	log screws, ¾" x 6".
67	steel rails (30'), 63 lbs. per yd.
67	fish plates, ¾" x 2½" x 20".
268	fish plates bolts, ¾" X 4".
3,000	spikes.
7,000	lin. ft. guard timber, 6' x 8", 28,000 ft. B. M.
1,500	guard rail bolts, ¾" x 14½".
150	log screws, ¾" x 12".
2,000	lin. ft. strap iron, ½" X 2½".
300	strap iron bolts, ½" X 6½".
300	blunt bolts for strap iron, ½" x 5".
¾	bbl. Portland cement.

It will be noted that laying the cross-ties cost about $3 per 1,000 ft. B. M., and that laying the guard rail cost about $3.60 per 1,000 ft. B. M.

The cost of 30 cts. per lin. ft. of single track is equivalent to $1,584 per mile for tracklaying.

To lay one "typical crossing" consisting of two cross-over tracks (one from each main track to a center track), comprising 218 lin. ft. of single track, with 5 frogs, from switches and outside guard timbers, with inside steel guard rails, cost as follows:

Hoisting, adzing and clipping cross-ties	$18.25
Laying rails, frogs and switches	40.00
Laying guard timbers	12.50
Laying steel guard rails	4.25
Total	$75.00

This is equivalent to 35 cts. per lin. ft. of the single track.

The iron superstructure of this elevated road consisted of Warren longitudinal girders, whose upper chords rest upon the top of Warren transverse girders, supported by six-segment Phoenix columns. The weights were as follows:

	Lbs. per lin. ft.
Transverse girders	200
Longitudinal girders	130
Bracing	8
"A" caliber columns	117
"B" caliber columns	140

The columns were erected by a gang of 7 men and a team of horses, using a derrick wagon. This gang averaged 39 columns, of 20 ft. each, erected per day, or about 4½ tons.

The same gang averaged 10 columns of 50 ft. each, or 3½ tons per day.

The columns were held temporarily in place by inserting iron wedges inside the rim of the base casting.

The cost of placing a 3,200-lb. base casting, on which the column rests, was as follows:

	Per casting.
Uncovering pier (15 cts. per hr.)	$0.35
Moving casting from sidewalk to pier (15 cts. per hr.)	0.40
Erecting derrick and setting casting (15 cts. per hr.)	0.60
Repaving, 25 sq. ft. (25 cts. per hr.)	0.50
Washing, tarring and bricking (25 cts. per hr.)	0.35
Refilling (15 cts. per hr.)	0.15
Preparing cement mortar (20 cts. per hr.)	0.10
Foreman and night watchman	0.50
Total labor	$2.95
¼ bbl. cement, at $1	0.25
¼ bbl. sand, at $1.25 per cu. yd.	0.05
32 brick, at $10	0.32
½ cu. yd. refuse carted away	0.38
2½ cu. ft. sand for paving	0.11
Coal tar, cement work, etc.	0.11
Oil for lamps, etc.	0.05
Grand total	$4.21

The above is for company work. Later on contracts were let for $3.75 per 3,200-lb. base casting, and the contractor put in 15 castings a day, as compared with 10 placed by the company's forces.

The girders were erected by a traveler on the structure, with a crew of 12 men and one engineman for the 15-hp. engine, which consumed ¼ ton coal per day. This crew raised 66 girders per 10-hr. day, or 200 tons.

The iron girders all being in place, the lateral bracing was then adjusted and riveted, and the columns very carefully plumbed with heavy iron plumb-bobs. Long columns were plumbed with a transit.

Two coats of paint were applied, the first being an iron ore paint and second being white lead. The painting cost $1.50 per lin. ft. of double track road (not including station buildings), of which 36.8% was for labor.

First Cost and Cost of Operation of Elevated Railways in Brooklyn and New York.*—The following table gives costs of building double track elevated railways in Brooklyn during three different periods:

Year.	1885 to 1888.	1888 to 1891.	1892 to 1903.
Miles of structure built	5.6	5.4	3.22
Number of stations	14	19	9
Total net tons iron	19,488	16,203	10,980
Average net tons per mile	3,473	3,001	3,055
Maximum net tons per mile	3,578	3,566	3,287
Minimum net tons per mile	2,907	2,842	2,824
Cost of iron per ton	$ 79.00	$ 68.68	$ 61.00
Cost of each foundation	187.70	140.00	93.50
Total cost per mile	542,441	332,352	297,599

In explanation of the high cost of foundations it should be stated that, from 1885 to 1888, a brick foundation pier with a bluestone cap

Engineering-Contracting, May 5, 1909.

and cast-iron base was used under each post or column. During 1888 to 1891 concrete was substituted for the brick, but the cast-iron base (below the street level) was retained. In 1892 and 1893, the cast-iron base was abandoned, and the columns were designed to rest directly on the concrete at the street level.

The 3.22 miles of structure built in 1892-1893 included 2,800 ft. of third and cross-over tracks, and the following were the average unit prices:

Excavation (per cu. yd.)	$ 0.50
Concrete (per cu. yd.)	7.00
Steel in structure (per net ton)	61.00
Timber (per M)	21.00
Steel rails per gross ton (85 lbs. per yd.)	31.00
Labor, laying single track (per ft.)	0.35

The following gives the detailed costs per mile of structure:

	Per mile of double track.
200 foundations (1,900 cu. yds. concrete) including bolts	$ 18,649
3,055 net tons iron in place	184,423
Double track, materials and labor	43,248
Stations	38,819
Engineering	9,934
Miscellaneous	2,526
Total	$297,599

There are 683,670 ft. B. M. timber per mile, in ties, guard rails, etc., which, at $21 per M, is equivalent to $14,357 per mile for timber.

It will be noted that engineering cost 3.35% of the total, and that the average weight of steel in the structure is 1,157 lbs. per lin. ft., and that the average span length of the plate girders is about 53 ft. Considering merely the cost of materials and labor, a span of 30 ft. would have been the most economical, and would have resulted in a saving of 5%, considering only the foundations and superstructure, but the longer span (53 ft.) was adopted to reduce damage to abutting property.

The maximum work of erection in 10 hrs. was 12 spans of 52 ft. each, weighing 315 tons; an average of 8 spans per day was easily maintained.

In the track laid prior to 1888, the ties were 6 x 8 ins., spaced 22 ins. c. to c., and the rails were 60-lb. A 6 x 8-in. guard timber was bolted each side of each rail. In 1888, the ties were made 7 x 8 ins., spaced 16 ins. c. to c., and the rails were still 60-lb. In 1892 an 85-lb. rail was adopted, to secure a longer life of the rail and to reduce the cutting of the rails into the ties, and the ties were spaced 15 ins. c. to c.

The contract prices for stations were about as follows in 1893:

	One stairway.	Two stairways.
Carpenter work	$3,095	$3,578
Sheet metal work	1,432	926
Painting and decorating	409	540
Plumbing work	225	296
Heating apparatus	225	295
Architectural work	2,100	2,200
Total	$7,467	$7,835

These were ordinary inter-track stations. It is a serious economic mistake to build two stations outside of the tracks, instead of one between, as it doubles not only the first cost but the cost of station service and maintenance. Station service and maintenance cost $2,400 a year per station.

Terminal stations, containing trainmen's rooms, etc., cost about double the above.

The cost of operating 16.9 miles of double track road, by steam locomotives, in Brooklyn in 1893 was as follows:

Maintenance of Way and Structures:	
Repairs of track and structures	$ 38,316.59
Repairs of stations, shops, etc.	13,032.29
Other expenses	425.30
Total	$ 51,774.18
Maintenance of Equipment:	
Repairs of locomotives	$ 40,317.29
Repairs of cars	53,039.53
Repairs of machinery and tools	1,730.76
Other expenses	11,847.72
Total	$ 106,935.30
Conducting Transportation:	
Wages of conductors and guards	$ 99,343.85
Wages of engineers and firemen	205,180.83
Fuel for locomotives	246,131.53
Oil and waste	6,085.92
Water supply	12,661.38
Other train expenses and supplies	16,585.73
Wages of station agents, gatemen, etc.	158,331.71
Station supplies	7,893.11
Wages of flagmen, switchmen, etc.	25,600.48
Other expenses	67,225.84
Total	$ 845,040.38
General Expenses:	
Salaries of officers and clerks	$ 32,247.55
General office expenses and supplies	809.80
Stationery and printing	6,746.94
Advertising	444.80
Legal expenses	16,574.05
Damage to property	915.08
Damage to persons	14,434.74
Telegraph maintenance and operation	1,195.69
Other expenses	14,595.55
Total	$ 87,963.70
Grand total operating expenses	$1,091,713.56

The operating expenses were 56.82% of the gross receipts.

There were 38,110,376 passengers carried.

There were 50 stations in the 16.91 miles.

There were 76 locomotives and 230 cars to operate the 16.91 miles of elevated road. This is equivalent to about 4.5 locomotives and 13.6 cars per mile of road, there being about 3 cars to each locomotive.

In *Engineering-Contracting*, Oct. 7, 1908, the cost of 85 miles of double track elevated railway built on Manhattan Island prior to 1880, was given as follows per mile:

Foundations, columns, superstructure and track	$288,400
Stations	60,000
5 locomotives, at $4,000	20,000
12 cars, at $3,300	39,600
Total	$408,000

It will be noted that the equipment cost nearly $60,000 per mile.

If the locomotives and cars cost the same for the Brooklyn lines, it will be seen that the cost of locomotive repairs was 13% of the first cost, for that item amounted to $530 per locomotive during the year 1893. The cost of car repairs amounted to $230 per car for 1893, which is about 7% of the first cost.

Our Oct. 7, 1908, issue gives the distribution of steel in the various parts of the Brooklyn elevated railways built in 1893, as follows:

	Per cent.
Columns	11.5
Transverse girders	20.5
Longitudinal girders (two tracks)	57.0
Station platforms	5.0
Bracing	6.0
Total	100.0

It is also stated that the locomotives weighed 45,000 to 56,000 lbs., the wheel base being 16 ft.

Cost of Foundations of the Boston Elevated Railway.—Mr. George A. Kimball gives the following relative to foundations for the Boston Elevated Ry., built in 1899. In general the foundations extend 10 to 12 ft. below the ground surface, to provide against being undermined by subsequent excavations for sewers, building foundations, etc. They are built of concrete in courses 2 ft. thick, stepped up with 6-in. offsets. The top course is 4 x 4 ft., and supports a cast-iron pedestal 12 ins. high to receive the steel post. Most of the foundations were built on the "cost plus a percentage plan." There were 1,133 foundations built, half at a cost of $260 each, and half at a cost of $700 each due to soft ground and interference with underground structures. This includes cost of pedestal castings, anchor castings and anchor bolts, which cost $22 per foundation; it also includes cost of moving underground structures which averaged $18 per foundation pier. The average foundation cost $480,

which is equivalent to $17.50 per lin. ft. of double track structure, or $91,000 per mile.

It will be noted that these foundations cost five times as much per mile of double track road as those in Brooklyn and New York, indicating extravagant design.

Cost of Elevated Railway and Subway, Berlin, Germany.—In 1901 an electric, double track elevated and subway railway was completed in Berlin, Germany. The motor cars each have two 4-wheel trucks, with axle loads of 6½ tons, axles being spaced 5.9, 15.0, 5.9 and 11.2 ft., in sequence. The weights of steel in different portions of the double track elevated road were:

Span, ft.	Lbs. per lin. ft.
39.4	810
49.2 (at stations, but not incl. stations)	1,145
54.1	940
68.9	1,210

There are 5.15 miles of double track elevated line and 1.22 miles of subway. There are 10 stations on the elevated portion and 3 in the subway.

The main power plant building is 73 x 132 ft., and houses 3 compound engines, each developing 900 hp. normally, or 1,200 hp. maximum. Trains are run on 2½ to 5 min. headway, at a maximum speed of 30 miles per hour. Each train consists of 3 cars (each 40 ft long), two of which are motor cars.

The cost was:

Construction	$4,400,000
Power house, rolling stock, equipment	950,000
Extras	800,000
Interest during construction	500,000
Total	$6,650,000

The construction cost of $4,400,000 was distributed thus:

1.221 miles double track subway, at $860,000	$1,050,000
5,154 miles double track elevated, at $650,000	3,350,000
6,375 miles total	$4,400,000

There were about 18,000 tons of steel used in the elevated (including stations), which is equivalent to about 1,320 lbs. per lin. ft. of double track elevated. The contract price on this work ranged from 3 to 4¼ cts. per lb. erected.

There were 2,200 tons of steel used in the subway.

Some of the other contract prices were:

	Per cu. yd.
Concrete in subway	$4.60
Brick foundation masonry	5.25
Arch masonry	7.85

It will be noted that the power house and equipment cost about 15% of the total cost, and amount to about $150,000 per mile of double track railway.

Cost of New York Subway Rock Work.*—By observation and through the aid of an assistant I have secured reliable data relating to every item of cost on several typical sections of the New York Rapid Transit Ry., including excavation, concrete, steel construction, etc.; and it is astonishing to find how high the labor cost of the work has been. The high cost may be attributed to several causes. In the first place, the contractors were compelled to employ union labor, much of which was inefficient. In the second place the foremen on this work were, as a rule, paid such small salaries that the best class of foremen were not kept. In the third place excavation and other work in crowded city streets is obviously made difficult; the supporting of pipes, tracks, etc., adding greatly to the cost in certain parts of the city. In fact, in the lower part of New York, where the material is all sand, I have found that 50 cts. per cu. yd. has been expended in shoring, bracing, etc. In the fourth place the light blasts required by city rules leave the tough mica schist in large chunks upon which much labor must be expended in gadding and sledging; for practically all the rock was broken to one or two-man size so that it could be hauled away in dump wagons.

The work that I am about to describe involved the excavation of about 125,000 cu. yds. of tough mica schist in the upper part of the city, where the streets are not crowded and where there were very few pipes to be supported. The width of the excavation was 41 ft., and the depth averaged about 30 ft. One trolley track ran along the center of the street and had to be supported the entire distance. This track supporting was accomplished at comparatively slight expense by using some ten second-hand railroad bridge trusses of 66 ft. span, which were moved forward as the work progressed. Five cableways, each having an average span of 400 ft., were used for hoisting the rock in self-righting buckets, which were dumped into patent dump wagons.

The average daily force employed was as follows:

	Rate per day.	Total.
4 foremen	$3.50	$ 14.00
80 laborers	1.50	120.00
10 drill runners	2.75	27.50
10 drill helpers	1.50	15.00
2 blacksmiths	2.75	5.50
2 blacksmiths' helpers	1.50	3.00
5 hoisters	3.00	15.00
1 compressor man	4.00	4.00
1 fireman	2.00	2.00
2 timbermen	2.00	4.00
3 waterboys	.75	2.25
20 teams	4.50	90.00
Total per 8-hr. day		$302.25

*Gillette's "Rock Excavation," p. 273.

The average output of this force was only 150 cu. yds. of rock per day.

	Wages per 8-hr. shift.	—Cost per cu. yd.— Average of 30 months.	Best month.
Drill runners	$2.75	$0.174	$0.150
Drill helpers	1.50	.100	.082
Blacksmiths	2.75	.032	.025
Blacksmiths' helpers	1.50	.018	.012
Compressor man	4.00	.016	.014
Firemen	2.00	.012	.014
Hoist enginemen	3.00	.100	.051
Carpenters	3.50	.008	.000
Timbermen	2.00	.024	.000
Waterboys	0.75	.012	.010
Laborers	1.50	.785	.745
Foremen	3.50	.102	.095
Teams (with drivers)	4.50	.620	.581
Total wages		$2.002	$1.779
Cu. yds. excavated		125,000	7,600

To the foregoing must be added the cost of fuel, explosives, maintenance, interest and depreciation of plant, etc., as follows:

	Cost per cu. yd.
1/30 ton coke, at $4.50	$0.150
0.6 lb. 40% dynamite, at 12½ cts.	0.075
½ exploder, at 4 cts.	0.020
Drill repairs (est'd at 50 cts. a day per drill)	.034
Installing boiler and compressor	.014
Interest and depreciation (50%) of $7,000 boiler and compressor plant	.028
Ditto for $3,500 drilling plant	.014
Total supplies, etc.	$0.335
Add total wages	2.002
Total	$2.337

To this sum should be added 3 or 4% to cover general expenses, such as office rent, bookkeeping, night watchmen, insurance on laborers, etc., which would bring the grand total to nearly $2.40 per cu. yd. of rock excavated. It will be seen by the description of the work and by the comparatively low cost of timberwork that the expense of supporting pipes and tracks was unusually low for such a city as New York. On the other hand, the cost of drilling was exceedingly high, being 28 cts. per cu. yd. for wages alone, if we include the blacksmiths' wages and half the wages of the compressor man and his fireman. The drills should be charged with about half the cost of the fuel, which adds 7½ cts. more per cu. yd., making 35½ cts. per cu. yd. for drilling, not including some 3½ cts. for drill repairs (estimated) and 1½ cts. for interest and depreciation. Adding these two items we have a total of 40 cts. per cu. yd. chargeable to drilling alone, which is exceedingly high for an open cut of this width and depth. It is a striking fact that each drill broke less than 15 cu. yds. of rock per 8-hr. day. The inefficiency of the laborers is also well shown by their output of less than 2 cu. yds. per man per 8-hr. day. It is true that they had to

do a great deal of gadding, sledging and hand drilling to break the rock ready to load into buckets; but anyone who saw the men at work must have been impressed with their slowness. The output of only 30 cu. yds. per day per cableway shows how the cableway output was limited by the drilling. The high cost of hauling is also noteworthy, for the average haul was but little more than one mile.

While it was difficult to get union laborers to do a fair day's work, I think that if the contractors along the subway had in all cases employed civil or mining engineers of known experience in rock excavation, a great deal of money would have been saved.

Cost of New York Subway Earthwork.*—This is a class of work exceedingly expensive, not only on account of the work of supporting of pipes, buildings and car tracks, but because of the comparatively small gangs that must be worked. This not only runs up the cost of superintendence, but due to the great number of foremen employed, many bosses are exceedingly inefficient. While the laborers receive high wages (1.50 for 8 hrs.), it will be noted that the foremen are paid altogether too low salaries to secure the best of their class. A good superintendent of railway excavation frequently receives $250 a month, and if he is worth anything, he is worth that. On extensive excavation, cheap foremen mean dear work, as the following illustrates quite clearly:

Case I. Uptown, where the streets were not congested. Soft earth, ploughed, loaded with shovels into patent dump wagons, hauled half a mile and dumped; 1.9 cu. yds. place measure per wagon load. Excavation 55 ft. wide, in the street, and ultimately 20 ft. deep. Snatch teams and hoisting engine used to pull loaded wagons out of the pit. Delays in hauling due to street blockades. Numerous pipes and conduits to be supported, necessitating carpenters, plumbers, etc. The following gives the cost for one month's work, including tearing up pavement:

Laborers	1,130 days at $1.50	$1,695.00
Teams, hauling and plowing	520 days at 4.50	2,340.00
Snatch teams	30 days at 5.00	150.00
Carpenters	180 days at 2.50	450.00
Engineman	22 days at 2.75	60.00
Fireman	22 days at 2.00	44.00
Engineman (night)	22 days at 2.00	44.00
Superintendent		100.00
Foremen	59 days at 3.00	177.00
Two timekeepers and load checkers		135.00
Three watchmen	78 days at 1.50	117.00
Plumbers, caulkers, etc		300.00
Total for 6,400 cu. yds. at 88 cts.		$5,612.00

The foregoing cost was at the beginning of the work, and under what might be regarded as favorable conditions. The following gives the general average of several jobs at a later period, and may be taken as being under, rather than over the actual cost, because all timber work and incidentals are probably not included:

*Gillette's "Earthwork and Its Cost," p. 176.

Case II. Conditions same as in Case I, except that excavation, car tracks, etc., required more support.

	Per cu. yd.
Labor excavating and superintendence	$0.50
Teaming	0.40
Materials and supplies	0.09
Labor on bracing and sheeting	0.06
Materials for bracing and sheeting	0.07
Labor on bridges and barricades	0.01
Materials for bridges and barricades	0.01
Taking up pavement	0.01
Labor for pumping and draining	0.02
Materials for pumping and draining	0.01
Labor on engines	0.04
Fuel for engines	0.01
Total	$1.23
Hauling away in scows	0.32
Grand total	$1.55

A charge of 60 cts. per wagon load, which was equivalent to 32 cts. per cu. yd. (as above recorded), was made for removing the earth from the water front on scows.

The subcontractor's prices for this earthwork averaged about $2 per cu. yd. On some sections as high as $2.50 per cu. yd. was paid, and in those sections the contractors found that it cost them $25 per lin. ft. of street to keep the car tracks in shape, due largely, however, to poor methods of management.

On downtown work, where the streets were not entirely torn up, but were kept planked over so as not to interfere with traffic, the cost of earth excavation was $3.65 per cu. yd. (See the following paragraphs.)

Itemized Cost to the Contractors of the New York Subway for Earth and Rock Excavation, Bracing, Concrete, Waterproofing and Steel Work.*—In view of the fact that the City of New York will doubtless construct scores of miles of subways for rapid transit, any data of actual cost of construction will be of great value to contractors and subcontractors who may bid upon subway work in the future. Then, too, other large cities will surely be forced to build subways similar to those in New York and Boston.

We have secured complete itemized records of the actual cost of labor and materials required to build several sections of the subway in New York City, and these records are now published for the first time.

We shall first give the methods and costs of building a half-mile section from the Post Office to the Battery. The excavation work was not done by the "cut and cover method"; that is to say, a trench was not dug in the street and left entirely open, as was the practice on nearly all subway work between the years 1902 and 1904. So much of a hue and cry had been raised against the open-cut method that when the contract for the Brooklyn Extension was drawn, the contractors were required to keep the streets continuously open for traffic, except at night time.

*_Engineering-Contracting_, Feb., 1906.

To meet this requirement the contractors devised the following method of operation: In the night time a short section of the street pavement was removed, stringers were laid down, and a plank roadway was laid upon the stringers. Then the excavation was proceeded with, underneath this plank roadway. In order to make the excavation, small shafts were sunk through the sidewalk at intervals of about a quarter of a mile. Through these shafts all excavated materials were removed and all construction materials were taken in.

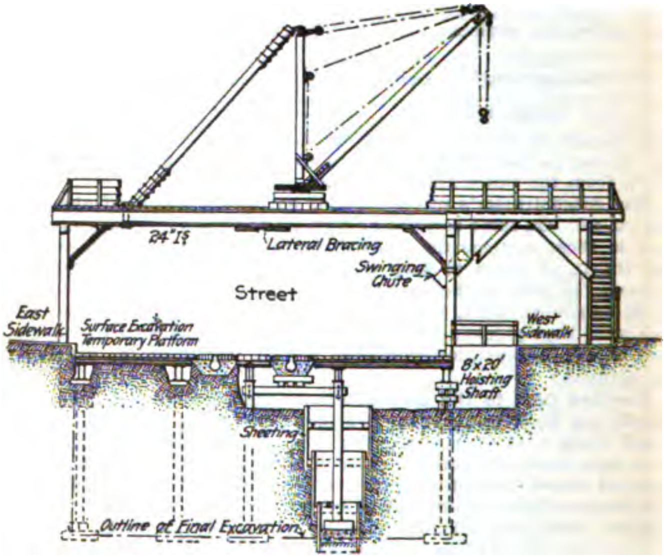


Fig. 10.—Excavation, New York Subway.

At each shaft a temporary bridge was built (Fig. 10) spanning the street, and upon this bridge were mounted the derricks and hoisting engines. Each overhead bridge consisted of a 52 × 60 ft. wooden platform carried by I beams, the whole supported by well-braced timber trestles set upon each curb line, as shown below. Each platform carried two stiff-leg derricks set opposite each other, also a hoisting engine and a spoil-bin with chutes. The derricks were operated during the daytime by compressed air, but at night the necessary power was supplied by a vertical boiler on one platform and an electric motor on the other.

The work of substituting timber platforms for street pavement was begun at the overhead bridges. Small strips of pavement

were removed at each end of the platform and shallow excavations made in which trenches were dug. Longitudinal 24-in. I beams were placed in each trench and blocked up on the trench bottom. The paving between the trenches was then taken up and a layer of earth removed to make room for the timber platform. This was composed of 8-in. I beams, spread 7½ ft. apart, with their ends resting on the girders. On this was placed 6-in. roadway planking. All this work was done at night and in such short sections that the street could be restored before daylight.

After the first section of platform had been built, a shaft 8 ft. square was sunk through the west sidewalk to a depth of 10 ft. From this shaft the upper part of the excavation was tunneled under the platform, the longitudinal girders being supported by posting down as the work progressed Similar posts and blocking were placed under the street railway. When sufficient headway had been secured, shafts 5 ft. square were sunk to the subgrade of the subway. A portion of the concrete floor of the subway was built in the bottoms of these shafts and a post erected to carry the girders. The temporary blocking under the railway conduits was then removed and replaced by saddle beams strung from the girders.

An alternative method for carrying the tracks and street surface was used where the excavation was obstructed by pipes and conduits. Surface platforms were built on each side of the street between the curb and the nearest street railway conduit. A lateral drift was then carried under the conduit and a needle beam inserted. These beams, which were blocked up against the conduit, carried on their outer ends longitudinal I beams which supported the inner edges of the surface platforms. The other edge of these platforms rested on the I beam girders supported by the blocking in the trenches at the curbs. After the earth between the drifts was removed, the needle beam shores were reinforced by jacks resting on continuous longitudinal sills. The posts were then set in shafts and replaced the jackscrews and blocking.

All of the excavated material was taken to the shafts and hoisted by the derricks to the overhead platform, where it remained until discharged through the chutes into wagons on the street below. The excavation was done by pick and shovel, cars being used to transport the material to the nearest shaft. These cars were either pushed by the laborers or drawn by a mule. The excavated material was sand, for the most part, very easy to dig. Indeed, much of the sand was used for concrete.

In the following tabulation is given the actual unit cost to the contractor of the construction of a section about one-half mile long of the Brooklyn Extension of the Rapid Transit subway of New York City. The period covered by these costs extends over sixteen months:

EARTH EXCAVATION.

(112,288 cu. yds.)

	Per cu. yd.	Total.
Labor	$1.60	$179,998
Materials and plant	0.32	35,590
Power	0.02	2,676
Dump charges (60 cts. per load)	0.25	27,934
Total unit cost	$2.19	
Grand total cost		$246,198
Bracing and Sheeting:		
Labor	$0.78	$ 87,466
Materials and plant	0.37	41,216
Total unit cost	$1.15	
Grand total cost		$128,682
Pumping and Drainage:		
Labor	$0.01	$ 8,878
Materials and plant	0.01	1,271
Power	0.01	1,059
Total unit cost	$0.03	
Grand total cost		$ 3,208
Bridges and Barricades:		
Labor	$0.10	$ 11,588
Materials and plant	0.14	15,423
Total unit cost	$0.24	
Grand total cost		$ 27,011
Backfilling:		
Labor	$0.01	$ 1,279
Grand total, earth excavation	$3.62	$406,379

ROCK EXCAVATION.

(760 cu. yds.)

Labor	$2.35	$ 1,783
Materials and plant	2.96	2,254
Power	0.40	301
Total unit cost	$5.71	
Grand total cost		$ 40,741

CONCRETE.

(Foundation Concrete, 8,827 cu. yds.)

Labor, mixing	$0.53	$ 4,669
Labor, placing	0.58	5,142
Materials and plant	0.02	211
Cement, sand, stone, etc	3.48	30,719
Total unit cost	$4.61	
Grand total cost		$ 40,741

Roof Arches, Side Arches, and Protection Concrete:
(6,664 yds.)

Labor, mixing	$0.82	$ 5,444
Labor, placing	0.84	5,623
Labor, setting forms	2.21	14,746
Labor, plastering arches	0.06	431
Materials and plant	0.18	1,176
Cement, sand, stone, etc	3.58	23,888
Total unit cost	$7.69	
Grand total cost		$ 51,308
Grand total unit cost concrete (15,491 cu. yds.)	$5.94	

STEEL WORK.

(Steel, 1,533 tons; cast-iron, 171 tons.)

Labor, trucking	$0.80	$ 1,364
Labor, placing	8.14	13,872
Labor, riveting	2.76	4,697
Labor, painting	0.70	1,197
Materials and plant	2.32	3,958
Materials, painting	0.24	415
Power	0.19	317
Grand total unit cost	$15.15	
Grand total cost		$ 25,823

BRICK BACKING.

(1,014 cu. yds.)

Labor	$8.56	$ 8,687
Materials and plant	2.03	2,063
Grand total unit cost	$10.59	
Grand total cost		$ 10,750

LAYING DUCTS.

(123,483 lin. ft. single duct.)

Labor	$0.01	$ 1,435
Materials and plant	0.05	6,321
Grand total unit cost	$0.06	
Grand total cost		$ 7,756

WATERPROOFING.

(98,074 sq. yds. single ply.)

Labor	$0.05	$ 5,563
Materials and plant	0.10	9,702
Grand total unit cost	$0.15	
Grand total		$ 15,265

WATERPROOFING.

(Brick in asphalt 1,337 cu. yds.)

Labor	$ 6.32	$ 8,457
Materials and plant	11.48	15,351
Grand total unit cost	$17.80	
Grand total cost		$ 23,808

The following table gives a summary of the total costs from August, 1903, to January 1, 1905, of constructing this section. In the preceding table no unit costs are given on the work of underpinning buildings, blocking, moving and relaying mains, supporting tracks, paving, station work, track work in tunnel and construction of a cross passage in Dey street. The net totals of these, however, are figured in with the other totals in the summary:

SUMMARY.

Labor	$443,268.13
Materials and plants	232,723.30
Dump charges (46,556 loads at 60 cts.)	27,933.60
Power (coal and electricity)	4,373.95
Labor charged to sewers	2,803.60
Total cost (not incl. cost of steel and iron)	$711,102.58

This is for half a mile of double track line.

During the excavation the contractor sold 12,924 cu. yds. of sand at 50 cts. per cu. yd., and 1,620 cu. yds. rubble stone at $1.00 per cu. yd. Deducting this total of $8,082 from the total cost of the work we have $703,020.58 as the net cost of the work, exclusive of the cost of the steel in posts and beams. The cost of track and ballast is not included, but that is readily estimated.

It will be noticed that in the tables giving the unit costs of the subway construction one of the main items is for materials and plant. In the following tabulation are shown the principal items and their cost which composed materials and plants:

MATERIALS AND PLANTS.

Earth Excavation:

	Total.
Small tools, etc.	$ 529
Illumination, etc.	3,119
Boilers, total 210 hp.	2,600
37 1 cu. yd. buckets	2,200
11 stiff leg derricks	2,750
20 flat cars	400
4,600 lin. ft. rail tram	306
2 Rand drills	600
2 Dake engines	700
3 Lidgerwood engines	1,680
3 electric hoists, "Maine"	3,750
1 electric hoist, "Lidgerwood"	1,500
166 M. ft. yellow pine lumber at $25	4,155
209 tons steel beams, in working platforms	10,470
Miscellaneous	550
Total	$35,590

Rock Excavation:

4 Rand rock drills	$ 1,200
1 Lidgerwood engine	560
1 stiff-leg derrick	250
760 lbs. dynamite	114
Small tools, etc.	130
Total	$ 2,254

Bracing and Sheeting:

2 Rand drills (without at.) for driving sheeting.	$ 500
24 hydraulic jacks, 1,264 tons capacity	4,049
1,436 M. ft. yellow pine lumber at $25	35,900
Small tools, etc	767
Total	$41,216

Pumping and Drainage:

5 Worthington pumps	$ 770
1 Lawrence pump	350
2 Edison draphragm No. 3 pumps	45
5 pumps, steam syphons	100
Small tools	6
Total	$ 1,271

Bridges and Barricades.

607 M. ft. yellow pine lumber	$15,187
Small tools, etc	236
Total	$15,423

Underpinning Buildings and Vaults:

1,323 cu. yds. rubble stone	$ 1,323
225 cu. yds. sand	112
872 bbls. Portland cement	1,378
165 gallons asphalt	19
442 sq. yds. asphalt felt	19
16 M. brick	115
124 gallons paint	124
Small tools, etc	37
Total	$ 3,132

Roof and Side Arch and Protection Concrete:

3,248 cu. yds. sand	$ 1,624
4,296 cu. yds. gravel	6,874
8,095 bbls. Portland cement	12,790
36 M. ft. yellow pine lumber at $25	900
371 M. brick	2,599
Small tools, etc	276
Total	$25,064

Brick Backing:

34 cu. yds. sand	$ 17
130 bbls. Portland cement	205
81 M. hollow tile brick	1,785
Small tools, etc	56
Total	$ 2,063

Duct Laying:

6,000 sq. yds. burlap	$ 270
123,483 lin. ft. single ducts	5,556
275 bbls. Portland cement	435
68 cu. yds. sand	34
13 sets mandrels	26
Total	$ 6,321

Waterproofing, Brick Laid in Asphalt:

869 M. brick	$ 6,083
401 tons mastic asphaltum	9,025
Small tools, etc	243
Total	$15,351

Waterproofing:

112,785 sq. yds. asphalt felt	$ 5,075
36,582 gallons asphalt	4,389
Small tools, etc	237
Total	$ 9,702

Placing and Riveting Steel Work:

2 "Lidgerwood" engines	$ 1,120
2 air compressors and receivers	1,400
1 hand power derrick	50
1 pneumatic drill	125
4 riveting guns	500
Small tools, etc	763
Total	$ 3,958

Painting Steel:

370 gallons cerion paint	$ 376
Brushes and scrapers	39
Total	$ 415

Supporting Tracks:

Sand, stone and cement	$ 301
68 M. brick	474
20 hydraulic jacks, 1,050 tons capacity	3,412
Total	$ 4,184

Block, Moving and Relaying Mains:

199 M. ft. yellow pine lumber at $25	$ 4,985
2 hand derricks	100
1 portable derrick, with boiler and engine	1,000
Pipe	26,186
Gates, valves and lead	1,871
Small tools, etc	1,699
Total	$35,841
Grand total for plant and materials	$232,723

We note that the cost of placing and riveting steel is given, but nothing is said as to the cost of the steel itself. The price of steel delivered in New York, ready for erection, may be estimated at 2½ cts. per lb., or $50 per ton. As there were 1,533 tons of steel, the total cost of the steel was $76,650. In addition, there were 171 tons of castings, which, at $40 per ton would amount to $6,840; and there were 1,014 cu. yds. of brick backing, the bricks for which would cost about $14 per cu. yd., or $14,200. The sum of these three items is $97,690 to be added to the $711,102 above given, making a total of nearly $810,000 for the section under consideration—half a mile of double track subway.

It will be seen that the full first-cost of the plant has been charged up against the various items. The cost of renewals of wornout parts was not obtainable, so that the only satisfactory method of estimating plant charges consisted in including the full cost of the plant.

In some items, as in Rock Excavation, the cost of plant is altogether too high, due to the fact that an expensive plant is charged up against a small amount of work.

It will be noted that the pumping item was very small; so also is "backfilling," because most of the excavated material was hauled away. The backfill was 6 ft. deep over the subway roof. All the excavated material not used for concrete or masonry, was hauled away in wagons to the docks, the haul being very short (about ½ mile) to the docks where the material was dumped into scows and hauled to sea. The charge made for hauling to sea in scows ("dump charges") was 60 cts. per wagon load, and about 1⅔ cu. yds. of earth constituted a load.

The total cost of earth excavation was $3.62 per cu. yd., which seems very high. However, the conditions must be considered, and among other things it must be remembered that the cost of supporting numerous water pipes and gas pipes is included. The excavation was 26 ft. deep, and 34 ft. wide along the line between stations.

The cost of power charged to the various items includes only the fuel and electricity consumed. Electricity was paid for at 4 cts. per kw.-hour.

All steel was painted with one coat of carbon paint; and all steel not imbedded in concrete received, in addition, a coat of white lead paint.

The cost of waterproofing is reduced to cents per square foot of single ply; but the waterproofing was actually laid 2 to 3 ply thick.

For the sake of comparison, we shall next give a summary of the costs of earth excavation on two sections in the lower part of New York City, where the open cut method of excavation was used. The rates of wages were practically the same as in the table on page 33; but the work was done between the years 1902 and 1904. The excavation was wider, being for a four track road, and cableways were largely used for delivering the materials from the trench into wagons. Some derricks were also used for this purpose. The streets were not always opened their full width, which necessitated a good deal of mining under the pavements and car tracks. The costs of excavation by this open-cut method were as follows on two sections which are designated as Contract A and Contract B.

	Contract A.	Contract B.
Cu. yds. excavation	105,070	252,870
Labor and teaming	$1.15	$1.20
Plant (all of first cost)	0.17	0.14
Power	0.12	0.09
Dump charges, at 60 cts. per load of 1⅔ cu. yds.	0.19	0.18
Labor and bracing and sheeting	0.34	0.18
Lumber for bracing and sheeting	0.21	0.11
Pumping and draining	0.00	0.06
Labor on bridges and barricades	0.03	0.02
Lumber for bridges and barricades	0.03	0.04
Labor, backfilling	0.06	0.04
Total per cu. yd.	$2.30	$2.06

The contractor, in each case, sold enough sand from the excavation to reduce the cost of excavation about 18 cts. per cu. yd., leaving a net cost of $2.12 for Contract A, and $1.88 for Contract B. The sale of this sand also reduced the dump charges, which would otherwise have been 36 cts. per cu. yd., instead of 18 to 19 cts. Had all the material been hauled to sea, the dump charges would have added about 18 cts. per cu. yd., making a cost of $2.48 for Contract A, and $2.24 for Contract B. It should be noted, however, that the full amount of the first-cost of the plant was charged against the excavation. The item of backfilling is not large because so small an amount of excavated material was replaced.

The lumber for bracing and sheeting was about half spruce, at $20 per M., and half yellow pine, at $25 per M.

The labor and teaming includes all wages and salaries.

The cost of erecting, riveting and painting the steel work was $16 per ton on Contract A, and $16.75 on Contract B.

The cost of labor in making the concrete was as follows:

Concrete foundations:

	Contract A.	Contract B.
Labor, mixing	$0.97	$0.94
Labor, placing	0.96	0.95
Power	0.14	0.16
Total	$2.07	$2.05
Concrete, Roof and Sides:		
Labor, mixing	$0.79	$0.91
Labor, placing	0.85	0.94
Labor, setting forms	2.01	1.20
Labor, plastering arches	0.16	0.23
Power	0.28	0.15
Total	$4.09	$3.43

It will be noted that these concrete labor costs are very high, and indicate poor management.

As to the cost of rock excavation, we may say that it should not exceed the cost of earth excavation by more than $1 per cu. yd. at the outside. Indeed, on one section of the subway involving the excavation of 125,000 cu. yds., the rock excavation cost $2.40 per cu. yd., but this did not include the first cost of the plant. In Gillette's "Rock Excavation," page 273 et seq., the actual cost of this rock work is given in great detail. (See page 1384.)

With the unit costs now available, any contractor can make a safe estimate of the cost of any future subway work in New York City. If the subway is built wider or narrower, the yardage will be altered, but the cost per cubic yard will not vary much. We are confident that few contractors or engineers would have looked for such high unit costs as are above given, and we are equally confident that with better management the costs could have been materially reduced. However, it is a fact and not a theory that confronts us, and we have given the facts to the best of our ability.

In the summary given above, the total cost of the labor from August, 1903, to January 1, 1905, is given as $446,071.73. It will

be of interest to show how this cost was distributed, and accordingly a table giving the rate of wages per eight-hour day, the time in days, and the total amount of wages is appended in Table XXV.

TABLE XXV.—RATE OF WAGES AND TIME.

	Rate.	Time.	Amount.
Civil engineers	$12.00	359	$ 4,308.00
Assistant civil engineer	6.40	526	3,366.40
Superintendents	5.28	780	4,118.40
Draughtsmen	4.00	354	1,416.00
Timekeepers	3.85	447	1,720.95
Clerks	2.88	1,080	3,110.40
Machinists	3.50	241	843.50
Engineers	3.50	291	1,018.50
Firemen	2.00	560	1,120.00
Watchmen	1.50	2,247	3,370.50
Night Watchmen	1.50	2,316	3,474.00
Laborer foremen	3.00	8,130	24,390.00
Laborers	1.50	106,023	159,034.50
Engine hoistmen	2.50	3,199	7,997.50
Steam drillers	3.00	278	834.00
Steam drillers' helpers	2.00	277	554.00
Nippers	.75	126	94.50
Blacksmiths	3.00	322	966.00
Blacksmiths' helpers	2.00	322	644.00
Rigger foremen	3.00	11	33.00
Riggers	2.00	702	1,404.00
Carpenter foremen	3.50	643	2,250.50
Carpenters	3.00	3,733	11,199.00
Bracers	2.00	32,918	65,836.00
Pipe foremen	4.00	1,495	5,980.00
Pipemen	2.00	10,433	20,866.00
Caulkers	3.00	3,139	9,417.00
Iron foremen	5.00	331	1,655.00
Ironworkers	4.50	3,725	16,762.50
Bricklayers	5.20	2,047	10,644.40
Mason foremen	4.50	225	1,012.50
Masons	4.00	1,077	4,308.00
Waterproofer foremen	3.00	245	735.00
Waterproofers	1.50	852	1,278.00
Paver foremen	5.00	13	65.00
Pavers	4.50	87	391.50
Rammers	3.00	36	108.00
Carts	3.00	12	36.00
Trucks and teams	4.50	11,900	53,550.00
Pipe superintendents	7.69	234	2,491.56
Tow horses and mules	1.00	2,441	2,441.00
Plumbers	4.00	100	396.12
Plumbers' helpers	2.50	30	67.50
Electricians	4.00	1,252	5,008.00
Splicers	3.00	463	1,389.00
Splicers' helpers	2.00	441	882.00
Painters	2.00	6	12.00
Track foremen	3.00	136	408.00
Trackmen	2.00	1,532	3,064.00
Total labor			$446,071.73

The prices of tools, machines and supplies will be found in the next paragraph.

Prices of Contractors' Tools, Machines and Supplies, New York.*—In estimating the cost of contractors' plants on the New York

*_Engineering-Contracting_, July 18, 1906.

subway construction, the engineers carefully obtained quotations on every kind of tool, machine, etc., in use. Although these quotations were secured in 1902, they are tolerably close to present prices in New York City, and may prove useful to contractors and engineers.

	Rate.
Adze	$ 1.10
Air compressor and receiver	700.00
Air hose, lin. ft.	0.80
Anvil, 200 lbs. at 8½ cts.	17.00
Asphalt, gallon	0.12
Asphalt felt, sq. yd.	0.04½
Asphalt heating kettle	30.00
Asphaltum, ton	22.50
Auger	0.90
Ax	1.10
Bar, claw	0.75
Bar, crow, 16 lbs.	1.30
Bar, pinch	0.75
Bar, tamping	1.00
Blasting battery	25.00
Block and fall outfit	16.00
Block, double wooden	4.00
Boiler, 60 hp.	750.00
Boiler, 50 hp.	575.00
Boiler, 25 hp.	350.00
Box, tool	12.00
Brick, M.	7.00
Brick buckets	0.50
Brick hammers	0.75
Brick, hollow tile, M.	22.00
Brick tongs	0.50
Brush, paint	0.75
Brush, wire	0.50
Bucket, 1 yard, dumping	60.00
Bullpoint	0.50
Burlap, sq. yd.	0.04½
Canthook	2.25
Cap, sheeting	2.50
Car, flat	20.00
Car, steel dump	40.00
Cement, Portland, bbl.	1.60
Chain, lb.	0.08½
Chisel	0.40
Derrick, hand power	50.00
Derrick, portable, with boiler and engine	1,000.00
Derrick, stiff-leg	250.00
Dipper	0.75
Drift pin	0.50
Drill, hand	0.50
Drill, pneumatic	125.00
Drill, Rand rock	300.00
Drill, Rand, without attachments	250.00
Drill, twist	1.25
Duct, single, lin. ft.	0.04½
Dynamite, lb., 40 per cent	0.15
Electric hoist, "Maine" double drum and 20 hp. motor and controller	1,250.00
Electric hoist, Lidgerwood double drum and 20 hp. motor and controller	1,500.00
Engine, "Duke"	350.00
Engine, Lidgerwood, double drum	560.00
Forge, blacksmith's	25.00

Forge, rivet	25.00
Furnace, with pots and ladles	35.00
Felt, asphalt, sq. yd	0.04½
Gouge	0.50
Grindstone	20.00
Hacksaw frame	0.85
Hammer, hand	0.50
Hammer, sledge	1.30
Hammer, striking	0.65
Hod, mortar	0.75
Hose, air, lin. ft	0.80
Hose, rubber, 1 in., lin. ft	0.15
Hooks, center	0.05
Jack, hydraulic. 7 ton	58.50
Jack, hydraulic, 45 ton	162.50
Jack, hydraulic, 60 ton	178.75
Jack, hydraulic, 100 ton	260.00
Lantern	0.50
Lead, lb	0.05
Level, hand spirit	0.75
Mandrels, set	2.00
Mop	0.60
Oiled suits	2.50
Pails, galvanized iron	0.50
Paint, cerion, gal	1.00
Pick	0.75
Pump, Lawrence 4-in., with Crocker-Wheeler 7½ hp. motor and starter	350.00
Pump, Worthington, 6 in. x 8½ in. x 6 in.	170.00
Pump, Worthington, 6 in. x 5¾ in. x 6 in.	150.00
Pump, No. 3 Edison diaphragm	22.50
Pump, steam syphon	20.00
Rail, tram, ton	15.33
Rammer, concrete	1.00
Ratchet	10.00
Reamer	1.00
Riveting dollies	5.00
Riveting "guns," pneumatic	125.00
Rope, Manila, lb	0.09
Rope, steel, 1¼ in., lin. ft	0.24
Rope, with hooks	0.50
Rubber boots	2.50
Sand screen	8.50
Saw, cross cut	3.00
Scraper (waterproofing)	0.50
Shovel	0.60
Smoothing iron	1.50
Steel beams, ton	50.00
Stocks and dies, set	8.00
Timber carrier	2.25
Timber dollies	2.50
Timber truck	25.00
Torches, banjo	2.00
Turnbuckles	1.25
Vise, pipe	7.20
Wheelbarrows, steel	7.00
Wrench	1.00
Wrench, chain	24.00
Wrench, monkey	1.00
Wrench, Stillson	3.00
Yarn, lb	0.05

Cost of Excavating and Bracing a Subway, Long Island R. R., Brooklyn.*—The work covered by our cost records was a section on

**Engineering-Contracting,* July 11, 1906.

Division 1, Atlantic avenue, about 2,500 ft. long, and occupied the year 1903, January to December inclusive. The work was an open cut, and the material encountered was sand and gravel containing a considerable number of small boulders. The digging was not difficult and was all done with picks and shovels.

Two tracks of the Long Island R. R. occupied the center of Atlantic avenue. One of these tracks was shifted to the side of the street, but the other was left in place as a service track for the dirt trains. Trains of flat cars were run onto the service track, and the earth was shoveled from both sides into the cars until a level about 3 ft. below the rails was reached. The service track was then shifted into one of the side cuts, and the center core was shoveled in. The excavation was then carried down on the other side of the track to 3 ft. below the rails, as before. The track was next shifted to the opposite side of the cut, and a third cut of 3 ft. was taken out. This method was pursued until the track had

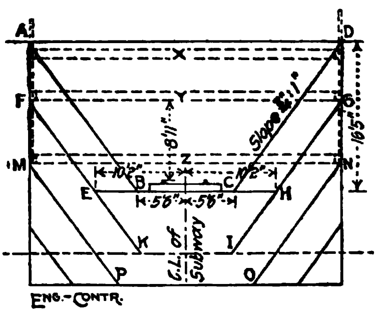


Fig. 11.

reached a depth of 16½ ft., as shown in Fig. 11, the shape of the cut then being ABCD (Fig. 11).

The next step was to drive 2-in. sheeting to depths F and G (Fig. 11). The two braces X and Y were then set, leaving a clearance of 9 ft., which was not sufficient to pass locomotives. A cable was therefore used to haul the cars ahead to the locomotive.

The next step was to excavate the two side cuts, ABEF and CDGH, by shoveling into the cars. After these side cuts were made, the track was shifted, first to one side, then to the other, and the section FKJH was excavated. The sheeting was then driven by pile drivers to the points M and N, and the brace Z was placed. In like manner the excavation proceeded until the full section of the subway was obtained, about 35 ft. wide and 27 ft. deep.

The 8 x 10 braces shown in Fig. 12 were spaced 15 ft. apart ·itudinally, and, in view of the great length of the braces, angle bracing was used, consisting of short timbers laid horizontally

and diagonally from the side of each cross brace to the middle of the ranger. These angle braces were about 14 ft. long.

The railroad company provided the cars and hauled the earth about 12 miles away, furnishing train crews. The contractor maintained and shifted the tracks, loaded the earth onto the cars, and did all the bracing. The following costs were the costs to the contractor, and do not include the cost of hauling the material away. The contractor complained of the poor train service furnished by the company, and the high cost of excavating bears out his claim of poor service. On the other hand, the railroad company is credited by outsiders with having given a "fair service." In any case, work done in this manner is nearly always subject to more or less delay in getting empty cars fast enough.

As above stated, the length of subway covered by our cost records was about 2,500 ft., averaging about 30 cu. yds. per lineal foot. A total of 75,000 cu. yds. were excavated in the year 1903,

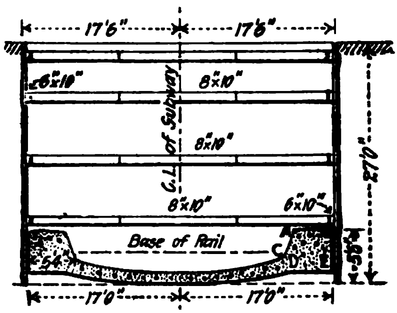


Fig. 12.

requiring 20,900 days' labor, or 3.6 cu. yds. per man per 10-hour day. Wages averaged $1.50 per day, making the average cost 42 cts. per cu. yd. for loading the cars. This does not include the cost of sheeting and bracing, which will be given later. The cost of the excavation by months was as follows:

EXCAVATION.

	Amount cu. yd.	Labor in days.	Pay-roll.	Cost per cu. yd.
January	4,818	1,637	$ 2,278	$0.47
February	4,089	1,433	1,992	0.49
March	11,005	2,554	3,552	0.33
April	5,381	1,508	2,132	0.40
May	4,230	1,321	1,844	0.44
June	3,035	1,127	1,573	0.52
July	4,002	990	1,379	0.35
August	5,383	1,664	2,617	0.49
September	8,118	2,450	4,307	0.54
October	10,327	2,392	3,658	0.35
November	8,550	1,930	3,023	0.35
December	5,953	1,898	3,083	0.52
Total	74,891	20,905	$31,438	$0.42

The cost of labor sheeting and bracing was as follows:

SHEETING AND BRACING.

	Labor days.	Pay-roll.	Cost per cu. yd.
January	507	$ 1,093	$0.23
February	482	1,091	0.27
March	827	1,766	0.16
April	874	1,859	0.35
May	782	1,859	0.42
June	860	1,999	0.66
July	1,005	2,363	0.59
August	812	1,894	0.35
September	700	1,613	0.20
October	800	1,831	0.18
November	644	1,510	0.18
December	1,316	1,742	0.29
Total	9,609	$20,548	$0.27½

It will be seen that the average wages paid for sheeting and bracing were $2.13 per day. As above given, the labor cost of excavating was 42 cts. per cu. yd., to which must be added the 27½ cts. per cu. yd. spent for labor on sheeting and bracing, making a total of 69½ cts.

The amount of timber used in sheeting and bracing the work done in 1902 and 1903 was as follows:

Between stations.	Ft. B. M. sheeting.	Rangers, braces, angles and uprights.
143 and 115	248,320	498,440
115 and 112	14,740	24,030
101 and 92	57,320	115,520
87 and 91	17,820	9,620
Total	338,200	647,610

This makes a grand total of 985,810 ft. B. M., or 7.94 ft. B. M. per cu. yd. of excavation, or 263 ft. B. M. per lin. ft. of finished subway, 3,700 ft. long.

From these data it is apparent that practically all the timber was left in place until the completion of this section of the subway. It is also apparent that the yardage of earth excavated in 1902 and 1903 was about 124,300 cu. yds. It should be borne in mind, however, that the labor costs above given for excavation and bracing include only the work done in 1903. The labor of sheeting and bracing for the two years was as follows:

Year.	Labor days.	Pay-roll.
1903	9,609	$20,548
1902	4,290	9,870
Total	13,899	$30,418

From this it appears that the labor costs of framing and placing the 985,810 ft. B. M. was $30.80 per M., and that each man averaged only 71 ft. B. M. per day. This is a very high cost for such work.

Since the timber itself must have cost approximately $30 per M. delivered on the work, we have the following estimate of the total cost of excavating:

	Per cu. yd.
Labor loading cars	$0.42
Labor sheeting and bracing	0.27½
7.94 ft. B. M. timber at 3 cts	0.24
Total	$0.93½

Of course, much of the timber would possess some salvage value after completing the work.

The cost of hauling the material away in cars and dumping is not available.

The cost of the concrete work was as follows:

	Proportions by parts.			Bbls. cement per cu. yd.
Cement.	Sand.	Gravel.	Broken stone.	concrete.
1	3	2½	2½	0.75
1	3	0	5	1.07 to 1.14
1	4	1½	2½	1.12
1	4	2	2	1.16
1	4	0	4	0.98
1	4	1	3	1.07
1	2½	0	3½	1.26
1	3	0	3	1.20
1	2½	1¼	2¼	1.46
1	3	1	2	1.30
1	3	1½	1½	1.04

It is interesting to note that in mixing many thousand yards of 1:3:5 concrete, it took 1.07 bbls. cement when mixed in the gravity mixer, as compared with 1.14 bbls. for the batch mixer, indicating a less perfect mixture in the gravity mixer.

Of the "1 to 8" concrete, about 13,880 cu. yds. were placed during the year of 1903, months of January to November inclusive, and 90 per cent of this was mixed with gravity mixers.

Of the "1 to 6" concrete, 5,320 cu. yds. were placed, of which 85 per cent was mixed with gravity mixers. The remainder, in both cases, was mixed in a "batch mixer."

The average size of a batch in a gravity mixer was 0.46 cu. yd., and the size of batch in the "batch mixer" averaged about 0.57 cu. yd.

There were 16,940 cu. yds. mixed in gravity mixers, requiring 2,860 days' labor mixing and 4,000 days placing the concrete. Wages were $1.50 a day, and the cost was 26 cts. per cu. yd. for mixing and 33 cts. for placing, making a total of 59 cts. per cu. yd.

During the month of August, when 2,800 cu. yds. were mixed, the cost was as low as 24 cts. for mixing plus 22 cts. for placing, making a total of 46 cts. per cu. yd. for mixing and placing. The gravity mixer averaged about 113 cu. yds. per day, with a gang of 19 men mixing and 26 men placing concrete.

With the "batch mixer," which averaged about 0.57 cu. yd. of concrete per batch, there were mixed 2,360 cu. yds. This required

970 days of laborers mixing and 740 days placing, at a cost of 59 cts. per cu. yd. for mixing plus 45 cts. for placing, making a total of $1.04 per cu. yd. for mixing and placing.

During the month of June the cost was as low as 40 cts. for mixing and 30 cts. for placing, or a total of 70 cts. per cu. yd., wages being $1.50 per day. The average gang was 14 men mixing and 11 men placing the concrete, and the average output was only 35 cu. yds. per day actually worked.

Even during the month of June, when the best record was made, the output was only 52 cu. yds. per day actually worked. This indicates very poor management. We refrain, therefore, from giving the name of the "batch mixer," to which an injustice would be done if its efficiency were rated according to this particularly poor record.

Of course, in the preceding discussion of the itemized labor cost of mixing and placing, the item of "mixing" includes all the work involved in delivering the materials to the mixer; while "placing" includes hauling the concrete away from the mixer.

In delivering the materials to the gravity mixer a Robins belt conveyor was used, which accounts in large measure for the lower cost of mixing with the gravity mixer.

The concrete was hauled away from the mixers in dump cars pushed along a track by men. The track was laid on top of the braces that supported the sides of the excavation. We are unable to find out why the conveying of the concrete from the batch mixer cost so much more than from the gravity mixer.

The foregoing costs relate to work done in 1903. During the year 1904, 20,000 cu. yds. were mixed in the 190 days worked by the gravity mixer gangs; the average number of men mixing being 15, and the number of men placing being 25.

The cost was as follows:

	Cts. per cu. yd.
2,950 days labor mixing, $4,870	24
4,760 days labor placing, $7,300	36
Total	60

During the best month, the labor cost was 16 cts. for mixing and 29 cts. for placing, or a total of 45 cts. per cu. yd.

During the same year of 1904, the batch mixer worked 153 days, averaging 46 cu. yds. per day. The average size of each batch was 0.44 cu. yd. The labor cost of 7,000 cu. yds. was as follows:

	Cts. per cu. yd.
1,910 days mixing, $3,175	45
1,740 days placing, $2,660	38
Total	83

It will be noted that in 1904 the cost of placing was practically the same as with the gravity mixer, and that the average gang on the batch mixer was 13 men mixing and 11 men placing.

Thus far we have not considered the cost of the labor on the forms, which was a large item. For the total 19,300 cu. yds. of

concrete placed in 1903 there were expended $16,800 for labor on the forms, which is equivalent to 87 cts. per cu. yd. of concrete. The total number of days' labor on the forms was 6,340, at an average of $2.70 per day. If we add this 87 cts. per cu. yd. for labor on forms to the 59 cts. for mixing and placing, we have a total of $1.46 per cu. yd. chargeable to labor on the concrete in this subway, where a gravity mixer was used. This is considerably below the cost of similar work on the New York subway.

As to the amount of lumber in the forms and the interest and depreciation of the plant, we have no record. Nor have we a record of the fuel consumed.

Cost of Cable Railways in Cities.—In Fairchild's "Street Railways" (1892), the following is given as an estimate of the cost of a double track cable line, based upon actual cost of some six lines. The line is 3 miles long.

	Total.	Per mile of double track.
Power House and Plant:		
Real estate	$ 10,000	$ 3,333
House, 100 x 175	25,000	8,333
Two engines and foundation	23,000	7,667
Boilers and settings	14,000	4,667
Brick smokestack (5 ft. diam. x 100 ft.)	5,000	1,667
Tension cars and tracks	2,500	833
Heaters, pumps, fittings, etc	3,000	1,000
Total power house and plant	$ 82,500	$ 27,500
General Street Construction:		
19,800 cu. yds. trench excavation at $0.75	$ 14,850	$ 4,950
2,755,000 lbs. cast yokes (350 lbs. ea.) at $0.015	41,580	13,860
880 carrying sheaves at $3.75	3,300	1,100
1,056,000 lbs. slot rails (50-lb.) at $0.025	26,400	8,800
1,185,000 lbs. track rails (60-lb.) at $0.0225	28,512	9,504
154,000 lbs. cast iron manhole covers and frames at $0.0175	2,695	898
10,000 cu. yds. concrete at $8.50	85,000	28,333
15,840 lin. ft. of double track laying at $1.00	15,840	5,280
22,200 sq. yds. granite block paving at $3.00	66,600	22,200
Sewer connections	9,000	3,000
32,180 ft. wire cable at $0.33	10,619	3,540
Total general street construction	$304,396	$101,465
Special Street Construction:		
Main vault at engine house and fixtures	$ 8,000	$ 2,667
Two end vaults with fixtures	5,000	1,667
Special street sheaves for summits of grades	1,500	500
Two grip switches	2,500	833
Two coach switches	1,000	333
One crossing	1,500	500
180 degs. of double tracked curve	9,000	3,000
Total special street construction	$ 28,500	$ 9,500
Rolling Stock:		
15 grip cars and grip at $1,000	$ 15,000	$ 5,000
15 coaches at $1,200	18,000	6,000
Total rolling stock	$ 33,000	$ 11,000
Grand total	448,396	149,465

With a cable speed of 8 miles per hr. for 19½ hrs., and trains on 4 mins. headway, each train would make 110 miles per day; and 15 trains would make 1,650 train miles, or 3,300 car miles per day. The daily operating expense would be:

	Total per day.
Depreciation of cable	$ 35.00
Repairs, track and buildings	6.00
Repairs, engines and line machinery	2.00
Repairs, grip and cars	7.00
House, track and cable expenses	6.00
Track service	8.00
Power and car house service	28.00
66 grip men and conductors at $2.00	132.00
5½ tons (2,240 lbs.) coal at $2.50	13.75
Water, oil and grease	3.25
Injury to persons and property	7.00
Licenses and taxes	7.00
General and miscellaneous expense	23.00
Total	$275.00

It is clear that Mr. Fairchild's data on repairs of track, buildings, and engines are founded on too brief a term of years to be of any value, for they total only $8 per day on an investment of $82,000 for power plant and $55,000 of rails alone. This expense of $2,920 per year ($8 per day) is not 2½% on the buildings, power plant and rails—a manifest absurdity.

It will be noted that the $35 daily depreciation of the cable is $12,775 per year on a cable whose first cost is $10,619. This is equivalent to a life of about 10 months. Mr. Fairchild states that the usual diameter of cables is 1⅛ to 1¼ ins. A 1¼-in. rope has a tensile strength of 80 tons, and weighs 2½ lbs. per ft. The average life of ropes of the best design, he says, has been 12½ mos., with an average service of 88,400 miles. The general average for the country has been about 8 mos., with mileage ranging from 40,000 to 150,000.

Cost of Constructing and Operating Cable Rys., Kansas City.—Mr. D. Bontecou gives the following relative to the cost of construction and operation of a cable railway in Kansas City. The road was finished in 1889. It comprises 8.54 miles of double track line, which is equivalent to 17.08 miles of single track. It was operated as four distinct lines, with cables 14,200, 29,500 and 31,000 ft. long respectively, driven from one power house, and a fourth cable 18,900 ft. long driven from a second power house. The cable speeds were 7.8, 9.9, 9.9 and 10.3 miles per hr. No grades exceeded 10%. The rope was 1¼-in. diam., carried on 12-in. pulleys, in a conduit 36 ins. deep.

The cost of construction was as follows:

		Total.	Per mile of double track.
1.	Real estate	$ 116,736	$ 13,664
2.	Underground obstructions	20,285	2,377
3.	Substructure	542,820	63,562
4.	Track and line machinery	276,075	32,331
5.	Paving	159,092	18,631
6.	Buildings	184,392	21,593
7.	Machinery	130,003	15,223
8.	Equipment	202,926	23,760
9.	Ropes and splicing tools	30,760	3,607
10.	Patents	12,951	1,522
11.	Engineering and miscellaneous exp.	83,017	9,719
12.	Discount and interest	146,931	17,201
	Total	$1,905,989	$223,190

The equipment comprised 99 combination cars, of which 61 were in constant service. The combination car contained the grip, seats for 40 people, and weighed 11,000 lbs. It ran on two 4-wheel trucks, with 22-in. wheels.

The machinery in the main power house consisted of three 200 hp. boilers and simple non-condensing engines. The machinery in the branch power house consisted of two 175 hp. boilers and engines. The total engine friction was 64 hp., the total resistance of all cables when no cars were on the line was 345 hp., and car resistance 166 hp. due to 61 loaded cars, or 2.72 hp. per car. About 30 hp. was used to supply electric light, etc. Total 541 hp., to which add, say 34 hp. for banking fires, etc., giving a grand total average of 575 hp. developed by two engines (one 38 x 48-in. and one 32 x 48-in. simple non-condensing) at the main power house. The coal (soft) contained 18% ash, and its cost was $2 per ton (2,000 lbs.). The consumption was 11.86 lbs. per car mile (combination car), or 2.1 per ton-mile.

For the fiscal year of 1892, the operating expense was as follows:

			Total.
1.	Car service and expense		$ 73,315
2.	Injuries to persons and property		5,087
3.	Secret service		529
4.	Repairs, cars		4,862
5.	Car house service and expense		9,620
6.	Maintenance, track and building		8,429
7.	Motive power:		
	Fuel	$17,407	
	Water	1,157	
	Oil and grease	1,041	
	Engine house service	7,786	
	Repairs, machinery	268	
	Engine house expense	299	
	Ropes	29,381	
	Rope service	3,066	
	Repairs of grips	1,789	
	Total motive power		$ 62,194
8.	Taxes		4,596
9.	General and miscellaneous		26,610
	Grand total (13.8 cts. per car mile)		$195,242
	Total car ("combination") mileage		1,415,366
	Passengers carried		5,318,410
	Average number cars run daily		61

The ropes lasted from 6 mos. on the short main line to 24 mos. on the branch line; the life of the four ropes averaging as follows: 20,000; 55,000; 68,000, and 130,000 miles respectively.

Since the line had been in operation only 4 years, the cost of car repairs, machinery repairs and track maintenance was obviously far below what a normal long period cost would be.

The operating cost was 13.8 cts. per car mile.

Cost of a Cable Railway in an Eastern City.—Mr. D. Bontecou gives the cost of a double track cable line in an Eastern city, as follows: The line was 3.05 miles long, almost straight, with 33,000 ft. of cable, and driven by a 300-hp. compound, condensing engine.

	Total.	Per mile of double track.
1. Real estate	$ 67,065	$ 22,027
2. Underground obstructions	46,500	15,264
3. Substructure and track	222,386	73,010
4. Paving	83,000	26,946
5. Power house and vault	103,032	33,811
6. Machinery and plant	65,563	21,533
7. Equipment (88 cars)	85,950	28,231
8. Rope	10,394	3,413
9. Patents	8,000	2,626
10. Interest during construction	22,136	7,254
11. Engineering, legal and miscellaneous	16,846	5,515
Total	$730,872	$239,630

Life of Cables and Cost of Operating Cable Railways, Chicago.—During the year 1898, the average life of 9 different cables, used on Chicago street cable railways, was 76,000 miles; but the life ranged from 44,000 miles to 120,000 miles per cable. The roads were level and with few curves, which accounts for the long life. Cables averaged 22,000 ft. long.

The cost of operation of cable and of electric lines in Chicago in 1898 was as follows:

	Cts. Per Car Mile. Cable.	Cts. Per Car Mile. Electric.
Transportation	4.537	5.731
Maintenance of way and bldgs.	1.563	1.889
Power	1.092	1.005
General expenses	2.508	2.493
Maintenance equipment	1.115	1.811
Total, cts. per car mile	10.815	12.929
Car miles	11,678,020	12,563,380

Use of trail cars on the cable accounts for lower transportation cost.

Labor Cost of Brickwork in Vaults of a Cable Railway.*—This work was done in 1892 in connection with the Third Avenue cable construction in New York City. The work was done by a subcontractor, who furnished the masons only, all the other labor and

**Engineering-Contracting*, Sept. 5, 1906.

materials being furnished by the general contractor for the Third Avenue cable construction. The laborers assigned to the sub-contractor were directly under the charge of the masons, although the general contractor's foremen on adjacent work gave some attention to them.

The sub-contractor was paid at the rate of $5 per 1,000 brick laid on all work except pulley vaults. For these he received $8 per 1,000 brick laid for single vaults and $10 for 1,000 brick laid for double vaults, these prices including cost of setting iron covers on the vaults. Twenty-one bricks were figured as making one cubic foot.

The masons were paid at the rate of 50 cts. per hour and they worked 8 hours per day. The foreman received 62½ cts. per hour and worked the same length of time as the masons. Laborers were paid $1.65 per 10-hour day, the extra 2 hours being spent in getting the materials ready, screening sand, mixing mortar, etc. During July and August there was no regular foreman, the work being looked after by the sub-contractor. The latter, however, did not perform the usual duties of a foreman, as the work was spread over a stretch of two miles, with additional work at 65th street and Harlem. In the summaries, where the sub-contractor really acted as foreman on the different works, these works are charged foreman hours for the time actually spent upon them by the sub-contractor.

Several causes tended somewhat to increase the cost of the bricklaying, the main causes being as follows: An unnecessarily exacting inspection; a frequent scarcity of brick, or such as the inspector would allow to be used, this scarcity of brick being primarily due to a brickmakers' strike; the fluctuating quantities of work on hand, due mainly to the slow arrival of iron for the cable railway, and to interferences by the surface cars. Then, too, the cost of common labor was high for that time (1892), due partly to the fact that the work was located in the most crowded part of New York City. The extra labor was required for rehandling materials.

The force account was carefully kept and the amount done each day was carefully measured by one of the engineers in the employ of the general contractor. The masons' time in the force account is the actual time paid for by the sub-contractor and includes the time spent in moving from one piece of work to another, but does not include time spent in waiting for brick or lost during showers. The laborer time includes all labor connected with bricklaying after the brick were dumped by the brick companies and the cement (in barrels) delivered by the general contractor near the mixing box. There were, however, occasional transfers by the laborers of brick, cement and sand from one part of the work to another, this transfer being caused by a local scarcity of materials.

The bricks used were mostly "Up River" bricks, measuring 8 in. x 3½ in. x 2¼ in.; the sand was Cow Bay sand from Long Island, and the cement was White's English Portland. An average of 447 bricks were used per barrel of cement.

PULLEY VAULTS.

Pulley vaults were placed for every 35 ft. of track. These vaults were to permit the oiling and repairing of the pulleys of the cable road. The single pulley vaults were placed outside of the track, but the double pulley vaults were placed between tracks wherever the tracks were the standard distance (10 ft. ½ in.), center to center. The single pulley vaults were constructed principally in the upper part of the Bowery, where a double vault could not be put in. The average height of both types of vaults was 4½ ft. The single vaults each contained about 40.1 cu. ft. of brick work, or 841 bricks, and the double vaults each contained about 47.7 cu. ft. of brick work, or 1,002 bricks. About ⅓ of the vaults had extra brick work for sewer connections. In building the vaults the cost of the mason work was necessarily large owing to cramped space in which to work, and owing to the fact that considerable time was lost in moving from one vault to another. There were generally three laborers to one mason. It will be remembered that the contract price for single pulley vaults was $8 for the mason work and $10 for the mason work for the double pulley vaults, the general contractor furnishing the materials. These prices include setting the iron cover. To do this last piece of work took one mason and three laborers one hour each, making the cost $1 per cover. The average labor cost of the brick work was $7.77 per cu. yd., divided up as follows. Masons, $4.02; laborers, $3.75.

During July to December, 96 days were worked, and 6,343 cu. ft. of brick work laid, at the following cost for labor:

	Per cu. ft.	Per M brick.
Mason	$0.15	$7.08
Laborers (mixers, helpers, tenders)	0.14	6.63
Total	$0.29	$13.71

The average number of bricks laid per mason per hour was 88, but during the best month the average was 96, and on the best day it was 106. The average number of brick per laborer hour was 25.

SPECIAL PULLEY VAULTS.

These vaults were constructed near the lower terminus of the line and were designed for the special iron work and pulleys required to operate the change from fast to slow cables. The average height of the vaults was 5 ft., their length was 10 ft., and all walls were 1⅓ ft. thick.

The work was done in December, 10 days being required for its completion. In that time 1,070 cu. ft. of brick work were built, taking 22,485 brick. The wages of the masons amounted to $112.31 and the laborers' cost was $82.42. The average number of brick laid per mason hour was 122; the average number per laborer hour was 45.

The cost per cubic foot of brick and per M of brick was as follows:

	Per cu. ft.	Per M.
Masons	$0.105	$5.01
Laborers	0.077	3.67
Total	$0.182	$8.68

The labor cost per cubic yard of brick work was $4.91.

THIRD CABLE VAULTS.

These vaults were for manholes to give access to the pulley scarrying the third cable around the special iron work on Park Row. The vaults had an inside length of 4⅝ ft., and a width of 2½ ft. All of the walls were 1 ft. thick.

The work on these vaults was done in December, 7 days being required to complete the brick work. In that time 418 cu. ft. of brick work was built, requiring the placing of 8,776 bricks. The total cost of the masons was $43.25, and the laborers cost $42.65. The average number of brick laid per mason hour was 128; the average per laborer hour was 34.

The cost per cubic foot of brick work and per M brick was as follows:

	Per cu. ft.	Per M.
Masons	$0.103	$4.93
Laborers	0.102	4.89
Total	$0.205	$9.82

The labor cost of the brick work per cubic yard was $5.53.

POSTOFFICE WHEEL VAULT.

This vault was constructed at the lower terminus of the line and was designed for the sheaves around which the cables pass. The work on the vault was done entirely under ground, the top being covered with 6-in. x 12-in. yellow pine timber to accommodate the street traffic. Kerosene lamps furnished the light to work by, extra labor being required to attend to the lamps. Two blowers, operated by two laborers, were used to keep the air fresh. However, excessively hot weather with insufficient ventilation had a serious effect upon the cost of the work. As there was no regular foreman in charge of the masons considerable loafing resulted, and the cost was consequently increased. In the construction of the arches of the vaults, the space between them and the roofing was so small that the masons were almost compelled to assume a prostrate position.

The height of the vault was 8 ft.; the inside dimensions were 19 ft. x 46 ft. The walls of the main vault were 1⅝ ft. thick. In addition, another vault 29 ft. long by 4⅝ ft. wide was built against the wall of the main vault. This vault had walls 1 ft. thick. The arches across the main vault were 19⅝ ft. long, were 1 ft. thick, and had a 3-ft. span and a 3-in. rise.

There were 2,812 cu. ft. of main walls built in 27 days (July and August), and the cost was:

	Per cu. ft.	Per M.
Mason	$0.136	$6.48
Laborer	0.180	8.56
Total	$0.316	$15.04

The masons averaged 86 bricks per hr., but the maximum was 146 bricks.

There were 745 cu. ft. of arches built in 7 days, and the cost was:

	Per cu. ft.	Per M.
Mason	$0.109	$ 5.18
Laborer	0.182	8.66
Total	$0.291	$13.84

The masons averaged 112 bricks per hr., but the maximum was 147. Laborers averaged 19 bricks per hr.

Cost of a Cable Railway for Freight Cars.—Mr. Edward Flad gives the following cost of a short inclined cable railway built in 1891 in St. Louis, for the purpose of taking freight cars (2 at a time) up a 6% grade to a brewery, 2,000 ft. distant from the main steam railway track. The rise is 95 ft. Switch tracks at both ends were of 63-lb. rails, but the cable railway track had 85-lb. rails. The rails rested on cast-iron yokes, 500 lbs. each, 3½ ft. c. to c. The slot rail was a Z-rail, weighing 53 lbs. per yd. The conduit was made of 1 : 2½ : 5 Portland cement concrete.

COST OF CONDUIT CABLE TRACK.
(1,872 lin. ft.)

Grading and Track:	Total.	Per lin. ft.
3,850 cu. yds. excav., at $0.58	$ 2,219	$ 1.19
942 cu. yds. concrete mtls. and labor, at $5.55	5,231	2.80
51 tons T rails (85-lb.), at $36.00	1,840	0.98
Freight on rails	179	0.09
32½ tons slot rail (53-lb.), at $50.00	1,627	0.85
Bolts, shims, etc.	497	0.27
Labor, tracklaying (except on concrete, which was $896)	947	0.51
Castings for street crossing	1,100	0.59
273,174 lbs. cast yokes, at $0.0155	4,234	2.26
53,338 lbs. manholes and covers, at $0.0175	933	0.50
16,276 lbs. sheaves and frames, at $0.067	1,085	0.58
29,053 lbs. rack castings, at $0.035	1,017	0.55
Extra castings, depression sheaves, etc.	661	0.35
Total grading and track	$21,570	$11.52
Paving for Conduit Track:		
80 squares granite blocks, at $18.75	$ 1,500	
Sand	250	
Labor	408	
Total paving for conduit track	$ 2,158	$ 1.16

Repairs to Pavement:		
300 squares macadam, at $3.75	$ 1,127	
50 squares gravel	212	
Total repairs to pavement	$ 1,339	$ 0.72
Cable	$ 704	$ 0.38
Total track, paving and cable	$25,771	$13.78
Grip Car	$ 2,470	$ 1.32
Hoisting Engine (not incl. foundation)	$ 7,100	$ 3.80
Total track, paving, equipment, etc.	$35,341	$18.90

SWITCH TRACKS IN UPPER AND LOWER YARDS.
(7,700 lin. ft.)

Track:	Total.
85 tons T rails (63-lb.), at $33.00	$ 2,805
Freight on same	298
Track fastenings	816
Switches, frogs, etc.	2,518
Stringers, ties, etc.	2,139
Plank	746
Total track materials	$ 9,323
Laying track, 7,700 ft.	6,474
Total track in place	$15,797
Paving:	
563½ squares macadam, at $3.50	$ 1,972
8.5 squares spalls	22
227 squares macadam, at $3.75	851
15,000 granite blocks, at $0.05	750
Granite pavers' wages	188
2,675 cu. yds. excav., at $0.30	803
Total paving	$ 4,586
Sewerage	$ 909
Tools	$ 830
Total track, paving, etc.	$22,120
Crossing gate, house, etc.	397
Miscellaneous	481
Grand total, 7,700 lin. ft., at $3.00	$22,978

The foregoing does not include engineering.

The work was done by a contractor, who received 15% on the cost of all labor, which 15% is included.

The engine hoists at the rate of 5 ft. per sec. when the grip car, pushing two loaded freight cars, is ascending. The grip car is permanently fastened to the lower end of the cable. The cable track is straight, except for a curve at the lower end. Sixty to 80 freight cars handled daily.

The entire cost of this plant, cable road and side tracks, was $58,319.

Cost of a Rack Railway, Pike's Peak.—Mr. Thomas F. Richardson gives the following relative to the Manitou and Pike's Peak Railway, built in 1890. It is a rack railway (Abt rack), 8.9 miles long,

with maximum grades of 25%, total rise 7,517 ft., 16° max. curve, total curvature 210° per mile. The gage is 4 ft. 8½ ins.; 40-lb. T-rails on hewn red spruce ties 7 x 8 ins. x 9 ft. The grading was done by contract, at 15 cts. for earth, 32 cts. for loose rock and 90 cts. for solid rock. These prices were much too low, and should have been 30% higher to yield a fair profit, although the grading was "paid for both ways"; i. e., if the contractor succeeded in moving a cubic yard of loose rock from cut to fill, he got 32 cts. for excavation and 32 cts. again in embankment.

The total cost of grading was $150,900, or $16,950 per mile, including log culverts and masonry abutments for 4 small bridges (20 to 30 ft. span). Laborers received $2 per day.

The following was the weight of iron and steel per mile of track:

	Lbs. per mile.
1,584 rack bars, at 87.8 lbs.	139,080
1,584 chairs, at 23.25 lbs.	36,830
3,168 rack-rail bolts, at 1.97 lbs.	6,240
3,168 wood screws, at 1.64 lbs.	5,200
1,584 cover plates, at 1.89 lbs.	2,990
3,168 spring washers, at 0.146 lbs.	460
352 T rails, at 400 lbs.	140,800
352 pairs angle bars (38-in.), at 32.75 lbs.	11,530
2,112 bolts (⅝ x 3-in.), at 0.48 lbs.	1,010
12,672 spikes (5½-in.), at 0.55 lbs.	6,970
Total iron and steel per mile	351,110
3,168 spruce cross-ties.	

The tracklaying cost $4,275 per mile, including the cost of planing the ties (9 cts. each), engine service and everything except engineering. Had the material been more simply designed, this cost would have been much less.

There were 7 switches costing $450 each complete with ties.

There were 4 locomotives, each weighing 26 tons when loaded with fuel and water. The round trip is made in 2 hrs. with a coal consumption of less than a ton.

The cars weigh 14,000 lbs., are 41 ft. long, seat 50 passengers. The train crew is one conductor and one brakeman; only one car in a train.

Cost of Conduit Electric Street Railways.*—Mr. A. N. Connett gives the following costs of a conduit electric street railway installed by him in 1895 at Washington, D. C. There were 21 miles of single track built. The following prices were paid for rails and splice bars:

	Per ton.
Wheel rails	$28.05
Slot rails	31.28
Guard rails for curves	46.25
Conductor rails	40.88
Joints complete, each $1.20	

**Engineering-Contracting*, July 14, 1909.

The cost per mile of single track was:

Rails of all kinds, at above prices	$ 9,031.54
215.5 tons cast iron (yokes, incubator frames, covers, etc.), at $28.19	6,054.75
Bolts, tie bars, clips, etc	1,518.82
Bonds for conductor rails	476.00
Tracklaying (all labor and hauling)	2,864.97
Temporary track	162.04
2,507 cu. yds. all excavation (except cable ducts), at $0.95	2,373.34
Sewer pipes and brick work for duct manholes	483.01
Cable ducts	1,032.65
Excavation for cable ducts	355.14
765 cu. yds. concrete for conduit, at $7.09	5,422.02
514 cu. yds. concrete for paving base, etc., at $4.52	2,258.74
6,375 sq. yds. paving (not including base)	7,996.20
Special track work and curves	3,805.04
Extra bills of street contractor	1,163.20
Removal of sub-surface obstructions	3,240.09
Total per mile of single track	$48,336.47

The item of "cable ducts" covered the following totals for the 21 miles of track:

10,616 ft. of 12 way duct at	$1.20
41 ft. of 8-way duct at	0.88
21,354 ft. of 4-way duct at	0.55
133 ft. of 2-way duct at	0.35

There were 9,207 cu. yds. of excavation for these ducts at 83 cts. per cu. yd.

The concrete for the conduit was 1 bbl. Portland cement, 12 cu. ft. sand and 22½ cu. ft. stone. The concrete for the paving base was 1 bbl. Cumberland cement, 10 cu. ft. sand and 20 cu. ft. stone.

The paving on the 21 miles of track was:

42,126 sq. yds. old stone block at	$0.80
91,716 sq. yds. asphalt at	1.50

The temporary track is a very low item, the authorities having permitted a flat strap-rail to be laid on the pavement by means of flat tie bars with special seats at their extremities. The streets of Washington are exceptionally favorable for the construction of conduit roads, being wide and having little traffic.

For comparison study the following New York City figures by Mr. William C. Gottschall, engineer in charge of construction of the Second Avenue Railroad Co. of New York:

	Per mile of Single track.
Labor, at $7.59 per lin. ft	$39,720.90
Insulators, at $1.40 each	696.53
Iron work, excluding yokes, at $1.83 per lin. ft	6,684.25
224.7 tons cast-iron yokes, at $25.30	5,678.68
Concrete	3,929.38
Hauling yokes and iron work	569.03
Total, without paving	$57,551.53

This does not include paving, special track work, feeder ducts, bonds, sewer connections nor temporary track. The item of labor, which is exceedingly high, includes digging trough, removing old track, repairing concrete, removing excess of earth, hauling all track material, and track laying.

Mr. Connett estimates the excess in cost of a conduit line over a trolley line as follows per mile of single track:

105 tons sheet rails, at $31.30	$ 3,287
40 tons conductor rails, at $41.00	1,640
210 tons cast iron, at $28.20	5,922
Bolts	600
Porcelain insulators	175
1,400 cu. yds. excess excavation, at $1.00	1,400
1,200 cu. yds. excess concrete, at $7.00	8,400
Sewer connections	2,000
Excess labor track laying	3,000
Special track work, excess	2,500
Total	$28,924
Removing sub-surface obstructions, say	8,476
Total excess cost conduit	$37,500
Deduct overhead trolley construction	2,500
Total difference in cost	$35,000

The removing of sub-surface obstructions is merely a rough estimate.

The data on cable railways, on the preceding pages, may be consulted with advantage.

Cost of Electric Railway, Denver, Colo.—Mr. John P. Brooks gives the following as the cost of a single track line built (1899) in Denver, Colo.:

	Per mile.
94½ long tons of 60-lb. T-rails, at $23.50	$2,220.75
360 pairs of 60-lb. angles, at 40 cts. (too low)	144.00
1,080 lbs. track bolts, at 2¾ cts.	29.70
32 kegs railway spikes, at $4.50	144.00
360 copper or plate bonds, at 25 cts.	90.00
2,000 ft. B. M. plank for culverts	42.00
2,640 Texas ties, at 50 cts.	1,320.00
180 ft. of curve and guard rails, at $1	180.00
Hauling ties and rails	130.00
Laying 1 mile of track	550.00
1 mile No. 0 trolley wire	325.00
88 cedar poles in place and painted, at $4.25	374.00
Overhead work incidentals, including hangers, insulators and ratchets ($60), span wire ($40), and labor ($50)	150.00
2,000 cu. yds. excavation for track trench, at 25 cts.	500.00
	$6,199.45
Add 5% for engineering	300.55
	$6,500.00
Add 2 switches, at $250	500.00
Total per mile	$7,000.00

It is apparent that this line was not laid in a paved street. It will be noticed also that the price of rails, etc., was lower then than now. The cost of power plant and buildings is not included, but may be estimated at $15,000 for a suburban line 5 miles long.

Where paving of streets must be done, use the data given in the section on Roads and Pavements.

Cost of Electric Railway, Third Rail Line.—Mr. Ernest Gozenbach gives the following relative to a first-class, third-rail suburban

line, 62½ miles long. Including switches and sidings, the number of miles of single track is actually 66. Of the 62½ miles, 6½ miles are laid in city streets.

	Total.	Per mile of line.
1. Excavation and embankment	$ 96,000	$ 1,536
2. Bridges, abutments and culverts	91,050	1,457
3. Two overhead railway crossings	64,000	1,024
4. Ties, 2,640 per mile, at 55 cts	96,250	1,540
5. Ballast, 2,200 cu. yds., per mile, at 80 cts	116,000	1,856
6. Rails, 70-lb. per yd., at $31 per ton delivered	225,000	3,600
7. Joints, spikes and bolts for 60-ft. rails	29,500	472
8. Labor on track, 56 miles, at $600	33,600	538
9. Labor in street track, 6½ miles, at $1,800	11,700	187
10. Farm and highway crossings	9,500	152
11. Wire fences, 24,000 rods, at 73 cts	17,500	280
12. Switches, special work, etc	21,000	336
13. Bonds, 24,000, at 61 cts. in place	14,650	234
14. Cross bonds and special bonding, at switches	2,000	32
15. Third rail, 70-lb. per yd., 56 miles, at $36 ton	131,000	2,096
16. Insulators, spikes and bolts, at 62 cts. in place	18,000	288
17. Joint plates, bolts and labor laying rail	9,800	157
18. Bonds, 15,000, at 73 cts. in place	10,950	175
19. Crossings and crossing cables	13,500	216
20. Trolley in streets, single-track span construction	24,000	384
21. Power station, 150 kw., at $120 per kw	180,000	2,880
22. Power station building, at $11 per kw	16,500	264
23. Transmission line, 55 miles, at $1,400	77,000	1,232
24. Sub-station, freight and depot buildings	24,500	392
25. Sub-station, railway apparatus	65,000	1,040
26. Batteries	80,000	1,280
27. Telephone line	9,000	144
28. Block-signal system	35,000	560
29. Stations and platforms	4,250	84
30. Switch and platform-lighting circuit	4,000	64
31. General office building	8,000	128
32. Car shops, shop tools, etc	24,000	384
33. Car bodies and locomotive body	49,000	784
34. Trucks and air brakes	27,500	440
35. Electric car equipment	76,000	1,216
36. Lighting and power apparatus and supply systems	70,000	1,120
37. Accidents, contingencies and insurance, 5%	89,000	1,424
38. Administration, superintendence, office expenses, engineering, etc., 5%	89,000	1,424
Total	$1,963,750	$31,429

This estimate does not include allowance for right of way, station ground and legal expense.

To reduce above costs per "mile of line" (62½ miles) to cost per "mile of track" (66 miles), deduct 5.3%.

Items 33, 34 and 35 must be added together to get the total cost of rolling stock, making $2,440 per mile of line.

Cost of an Electric Street Railway, Chicago.—The following was the cost of a mile of double-track street railway in Chicago in 1895:

	Per mile dbl. tr.
283 tons (90-lb.) rails, at $33.00	$ 9,339
4,224 oak ties (5 x 8-in. x 7-ft.), at $0.38	1,605
352 cast welded joints, at $3.50	1,232
1,760 tie rods, at $0.15	264
33,792 spikes (½ x ½ x 4½), at $0.01	338
42,240 ft. wood filler	2,112
Labor at $1 per lin. ft. of double track	5,280
Total, exclusive of pavement materials	$20,170
10,560 sq. yds. cedar blocks, at $0.30	3,168
146 cu. yds. sand, at $1.25	183
435 cu. yds. broken stone, at $1.50	668
10,560 sq. yds. gravel and dressing, at $0.08	845
10,560 sq. yds. 2-in. hemlock boards, at $0.08	845
Total	$25,879

The above does not include the overhead system.

Cost of an Interurban Trolley Line.—Mr. Gilbert Hodges gives the following estimate of cost of an interurban electric trolley railway, based upon experience in New England in 1902:

	Per mile single track.
Roadbed, Land, Etc.:	
14,300 cu. yds. earthwork, at $0.45	$ 6,435.00
325 cu. yds. rock, at $1.75	568.75
3 acres clearing and grubbing, at $75.00	225.00
3,000 cu. yds. gravel ballast, at $0.50	1,500.00
640 rods wire fence, at $1.00	640.00
Pipe culverts	50.00
Masonry for bridges and culverts	1,000.00
Wooden and steel bridges	1,300.00
Land for private right of way	1,000.00
Total roadbed, land, etc	$12,718.75
Track:	
110 tons T-rails (70-lb.), at $31.50	$ 3,465.00
360 continuous rail joints, at $1.54	554.40
2,640 chestnut ties (6 x 6 ins. x 8 ft.), at $0.54	1,425.60
5,870 lbs. spikes, at $0.0225	132.07
720 bonds in place, at $0.615	442.80
17 cross bonds, at $0.50	8.50
Teaming material	270.00
Labor laying track	1,056.00
Total track	$ 7,354.37
Overhead System:	
Poles (35 ft.), brackets, cross-arms, etc., in place	650.00
Trolley wire and overhead material in place	1,100.00
Direct and alternating current feeders in place	1,750.00
Block signal and telephone systems	2,000.00
Total overhead system	$ 5,500.00
Engineering and Superintendence	$ 600.00
Grand total	$26,173.12

This does not include buildings, power, equipment, interest during construction, etc.

Cost of Third Rail and Trolley Lines Compared.—"Electric Railways" (1907), by Sydney W Ashe, contains the following costs of third-rail and of trolley lines, as estimated by Thomas Conway, Jr.

The estimated cost of a third-rail line is as follows per mile of single track:

Item.	Per mile.
1. 2,640 ties, at $0.75, delivered	$ 1,980.00
2. 2,200 cu. yds. ballast, at $0.80	1,760.00
3. 123.2 tons rails, at $31.00	3,819.20
4. Joints, spikes and bolts	500.00
5. Labor on track	600.00
6. Farm and highway crossings	150.00
7. 640 rods wire fence, at $0.75	467.20
8. Switches, special work, etc.	300.00
9. Bonding	400.00
10. 61.1 tons third-rail, at $36.00	2,199.60
11. Insulators, spikes and bolts, at $0.62	109.12
12. Joint plates, bolts and labor laying rail	175.00
13. Power station	3,000.00
14. Power station building	275.00
15. 7,000 lbs. transmission line copper (500 pr. triple-strand), at $0.2005	1,403.50
16. Pole brackets and insulators for transmission line	450.00
17. Sub-station; freight and depot buildings	2,000.00
18. Sub-station railway apparatus	1,000.00
19. Telephone line	150.00
20. Block signal systems	500.00
21. Platforms	100.00
22. Switch and platform lighting circuit	70.00
23. General office building	125.00
24. Cars	5,500.00
25. Accidents, contingencies, etc., 5%	1,500.00
26. Administration, engineering, etc., 5%	1,500.00
Total	$30,033.62

The estimate for a trolley line is essentially the same, except for the following items:

Item.	
4. Joints, spikes and bolts	$1,000.00
9. Bonding, 35.2 bonds, at $0.75 in place	264.00
10. Trolley wire (4/0), 3,382 lbs., at $0.198	669.63
11. Brackets for trolley poles, 52, at $1.50	78.00
12. Constructing overhead work	600.00
16. Trolley poles, 52, at $7.50	390.00
Total	$3,001.63

The total of the corresponding items (4, 9, 10, 11, 12 and 16) for third rail is $3,659, an excess of only $657 over the trolley line.

Mr. W. C. Gottschall gives the following estimates made by Mr. Maurice Hoopes of the difference in cost between a third rail and a trolley line:

THIRD RAIL LINE.

	Per mile
Extra length (15 ins.) of 500 ties, at $0.075	$ 37.50
500 insulators and fastenings, at $0.50	250.00
62.86 tons (80-lb.) low carbon rail, at $35 + $2 frt.	2,325.82
176 rail joints, at $0.60	105.60
352 bonds (425,000 cir. mil.) in place, at $1.00	352.00
200 ft. cable for crossings (1,000,000 cir. mil), etc., at $1.20	240.00
Laying rail	100.00
Total	$3,410.92

TROLLEY LINE.

(Span construction, and assuming one line of poles chargeable to transmission line.)

22,774 lbs. copper (equiv. to 80-lb. rail), at $0.17	$3,871.58
50 chestnut poles (8-in. x 30-ft.), at $5.00	250.00
Labor and materials for erecting	300.00
Total	$4,421.58

Mr. W. B. Potter's estimate of the cost of a protected third rail is as follows:

	Per mile.
66 tons (75-lb.) third rail, at $43.00	$2,840.00
528 reconstructed granite insulators, etc., at $0.40	211.00
352 bonds (No. 0000 G. E. 9" Form B), at $0.38	134.00
21.71 tons channel iron (6-in., 31½-lb.) guard, at $45.00	1,248.00
792 milleable iron supports for channel, at $0.36	286.00
176 malleable iron fish plates and bolts for channel, at $0.25	44.00
Labor of installation, including drilling rails and channel	900.00
Total	$5,663.00

Cost of Labor and Materials in Building Two Electric Railways.*— Mr. Daniel J. Hauer gives the following:

It is difficult to keep accurate records of costs of all details, owing to the methods generally pursued in carrying on the construction of electric roads. The majority of lines are built within city limits, thus allowing only a short section of the street to be torn up at a time, and this necessitates one gang doing several different kinds of work in a single day. Consequently we find the "common labor" item covering a number of details; instead of the cost of each being listed by itself.

This reason still holds good and the writer regrets that this is the case in the data he will give in this article. Even though this is so, several valuable lessons can be learned from the records and they may serve to guide some engineers and contractors on future work.

The two examples given are descriptive of construction done in a Southern city, during a year when labor was being paid a comparatively high wage, out-of-door work being plentiful, and a job obtained easily. This, of course, added to the cost of the work.

*_Engineering-Contracting_, February, 1906.

Example I.—Example I was done under a contractor on "force account," that is, at cost for labor plus a percentage. The work consisted of tearing up and partially destroying an old cable track and relaying the new electric roadbed. The old cable track rails and slot rails were taken out, and part of the concrete conduit and cast-iron yokes destroyed and filled in, then new ties and rails were laid and the street paved. The overhead work was not disturbed, so we present only the cost of track work. Unfortunately the cost of the various details was not kept separate, so we cannot give the cost of tearing up track, but can only show the total cost of common labor.

The working day was 10 hours and the following rates of wages were paid per day:

Superintendent	$12.00
Paymaster and assistant superintendent	5.00
Material man	4.00
Assistant material man	2.00
Timekeeper	3.00
Foremen	4.50
Assistant foremen	2.50
Laborer	1.50
Water boy	1.00
Laborers in the iron gang	1.65
Watchmen	1.50
Bonders and blacksmith	3.00
Helpers	1.75
Block pavers	5.30
Rammers	3.90
Stonecutter	6.00
Cart and driver	2.75
2-horse team	5.00
4-horse team	10.00

The pavers, stonecutter and rammers were union men, hence the two first named worked but 8 hours and the rammers 9 hours.

About a mile and one-half of track was laid, the total costs of labor and materials being:

Labor	$20,518.64
Paving	817.44
Paving materials	762.07
Gutters	341.26
Hauling	452.47
Permits from city	199.88
Engineering department	201.34
Rails, ties, angles, plates, bolts, etc.	12,532.97
Miscellaneous supplies	95.32
Total	$35,921.39

The rail laid was of the girder type weighing 107 lbs. to the yard, or 168.14 gross tons per mile. The height of the rail was 9 ins., while the base was 5½ ins.; the length of the rail section was 60 ft. The angle plates were 32 ins. long with 12 holes; the tie rods were 1½ ins. by ½ in., spaced every 6 ft. The two were spaced 2-ft. centers, while the spikes were 5½-in. by 9/16-in. The bonds were 10 ins. concealed.

The cost of the material was:

	Per lin. ft.
Rail, tie rods, spikes, plates, nut locks, bolts	$1.3894
Bonds	.0244
Tie	.2425
Handling from cars	.0020
	$1.6583

The cost of labor for tearing up the old track, excavating, laying and bonding for new and filling in ready for the pavers was $2.581 per lin. ft. of track.

The cost per lineal foot of track for paving materials was $0.10 and for labor was $0.108, making a total cost of $0.208.

The cost per lineal foot of track for the miscellaneous items, enumerated above, was $0.17; this makes a total cost per lineal foot as follows:

Material	$1.658
Labor (common)	2.581
Paving, including labor	.208
Miscellaneous	.170
Total	$4.617

The paving was granite block paving with large flag stone laid at street crossing for foot pavement. The majority of the blocks taken up from the old track were used, only about 10% of new blocks being substituted. The blocks were laid in sand, and cinders in wet places. The cost per square yard of paving was $0.19, being 10 cts. for labor and 9 cts. for materials.

Example II.—This work was identically the same, replacing a cable roadbed with girder rails for electric track. The cable road was of similar construction, but the work was done by the railroad company's own forces, except the paving, which was let to contract, the company furnishing materials. The amount of work done was a little more than a mile of single track, yet in both cases the work was for double track in the heart of the city, where street traffic was heavy.

The prices paid labor in this case were as follows:

Superintendent	$3.33
Foremen	2.50
Assistant foremen	2.25
Sub-foremen	2.00
Pavers	4.75
Rammers	3.50
Blacksmiths	1.90
Bonders	1.70
Surfacers and leaders	1.75
Laborers in iron gang	1.60
Laborers, including helpers, watchmen, etc.	1.40
Water boys	.75
Cart and driver	2.50
One-horse team and driver	3.00
Two-horse team and driver	5.00
Team and driver for dragging rails	3.75
Four-horse team and driver	8.00
Team for hauling rails	9.00

The total cost for labor and all materials was as follows:

Labor	$ 8,235.77
Paving	2,652.47
Paving materials	1,791.58
Gutters	106.21
Hauling	796.16
Permits from city	120.75
Engineering department	133.53
Rails, ties, angle plates, bolts, etc.	9,946.80
Miscellaneous supplies	105.79
	$23,889.06

The paving was done by contract, the railroad company furnishing all the materials, the contractor simply doing the labor of laying the Belgian blocks. There was 5,894.3 sq. yds. of paving, the contract price being 45 cts. per sq. yd. The cost of new materials per square yard was 31.4 cts., making a total cost per square yard of 76.4 cts. The paving in all cases ran 2 ft. outside of rail. This makes a cost per lineal foot of track for paving of 74 cts., being divided as follows: 44.2 cts. for the labor of laying and 29.8 cts. for materials. All the blocks were laid in sand, there being no other foundation.

The cost per lineal foot of track for track materials was the same as in Example I, namely $1.658.

The miscellaneous cost, such as hauling, permits, gutters, etc., per lineal foot of track was 21 cts.

In this case the labor cost of the work can be divided under several heads, but still such division as should be made, cannot be given, as the records were not kept with such an idea. The labor costs per lineal foot of track were:

Superintendence	$0.005
Foremen	.095
Laying and surfacing rails	.195
Labor of tearing up cable track, excavation, refilling, spacing ties, etc.	1.030
Watchmen	.010
Water boys	.016
Blacksmith work	.012
Bonding	.009
	$1.372

This makes a total cost per lineal foot of single track as follows, and allows of comparison with similar cost in Example I:

Material	$1.658
Labor (common)	1.372
Paving, including labor	.740
Miscellaneous	.210
	$3.980

It would seem from these figures that the company forces tore up the old cable road bed and laid the electric road for 63.7 cts. less per lineal foot of single track, or a difference of $3,363.36 per mile. This, at a glance, seems like an extraordinary difference, and for that reason it would be well to analyze these records.

The first thing to be noted is the great difference in the wages of various men, the contractors paying the larger wage. The difference in the compensation of laborers was 10 cts. This was made up by the railroad company giving each man two car tickets daily, one for use in the morning and the other for evening use. The cost of these tickets was not included in the company's records. It was considered that there was no direct cost to the company, but such an idea is certainly erroneous. It would seem that at least 5 cts. should be charged for these two rides, making a total charge of about $300. The other differences in wages are very hard to estimate, as the details of time on the two jobs could not be obtained.

The contractor has, in some cases, charged very high prices for some of his men, such as superintendent, foremen and some others. Some of these high rates were made necessary, as the men were paid full time, whether the weather permitted work or not, and as wages could only be charged the company when work was actually done, a higher rate than was paid was billed. Then, too, some of the wages paid by the company were very low, as foremen, blacksmith, bonders and a few others. The company failed to make a charge against their work for a pay master, material man and timekeeper. The roadmaster of the railroad and one or two other officials spent the greater part of their time in supervision of this work, yet no charge was made for this. All of these things would add materially to the cost.

Another matter, worthy of note, is that the contractors were only doing one stretch of work at a time, while the railroad company had as many as six jobs going on simultaneously. This reduced the cost of superintendence, blacksmithing and a few other items for the company, while the contractors were compelled to charge full time.

Another consideration was the class of work done. The contractor had no object but to give the best of work, the more it cost the greater his profits; but this was not so with the company's forces. Specifications were not lived up to, but rather ignored, and when difficulties were encountered, specifications were changed to suit the conditions. One foreman expressed the situation tersely when he said: "Anything goes with the company." Repairs to the work were necessary within a few months. As is always the case, cheap foremen do indifferent work, and foremen's salaries were small.

The percentage paid the contractor in Example I was 10%, hence his profit per lineal foot of track was 45.6 cts. Deducting this from his cost to the company we have $4.161.

Taking into consideration all of these facts, and it is more than doubtful if the cost of the work by the company's forces was less than that of the contractor. It will also be noticed that there was no charges for plant, and also for clerical hire, although clerks from several departments did extra work on account of the reconstruction.

The writer believes that this is another lesson against such work being done by company's forces instead of by contract. He would not be understood as advocating having the work done by a con-

tract on the percentage basis, as both the costs of these examples are high, but it would be much more economical to let the work at contract. There would no doubt have been a number of responsible contracting firms only too glad to do these jobs for less money than they cost the railroad company. If the work was too irregular to let it upon a unit basis, or too uncertain to make it a lump sum job, it could have been contracted for, at cost plus a fixed sum. Then there would be no object for the contractor to "salt" the job, or even prolong the time or skimp the work. There is certainly much food for thought in the above figures.

The bonding of the rails on electric track is an important detail of the work. The labor necessary consists of reaming the hole out in order to make the contact good and in placing and tightening up the bond. The cost of labor and material per lineal foot of track for bonding has been given, but it may be of interest to consider the cost per joint or bond. The bond used, was a 10-in. concealed bond, that is a bond entirely covered up by the angle plate. The cost of the bonds, apiece, was 73.2 cts. In Example I, with bonders' wages at 30 cts. per hour, the cost of labor per bond was 41.7 cts., making a total cost of $1.149. In Example II, with wages at 17 cts. per hour, the labor cost per bond was 24.5 cts. giving a total cost of 97.7 cts. This does not include the expense of putting on the angle plate and tightening up the bolts, as that is listed in the records of laying iron.

Both jobs were done in good summer weather. Traffic was maintained over one track while the other track was being rebuilt. No record was kept of the cost of laying these cross overs, consequently they were not charged against the work.

The management and organization of the forces was not up to the standard of our best contracting firms. A large per cent of the laborers were foreigners and they worked under sub-foremen or assistant foremen of their own nationality. This made it possible for the men to lose and waste time. Frequently instructions were misunderstood, so work was done wrong only to be changed. Some foremen were kept at work, not from their ability to handle men and obtain good results, but because they could furnish new laborers when they were needed. It was also possible for discharged men to go from the job at which they were laid off to another piece of work being done by the company and obtain employment. Any contractor knows the cost of such proceedings. They cannot be calculated but they show up on the wrong side of the ledger at the end of a season's work.

Cost of Street Railway Track with Rubble Concrete Base, Ft. Wayne, Ind.*—The track was single track in paved street, with sidings and turnouts, and the work consisted in excavating some 8 ft. wide and from 1 to 3½ ft. deep, placing the concrete, laying track, and repaving. The construction is shown by Fig. 13. The costs as given by Mr. H. L. Weber, chief engineer, Ft. Wayne & Wabash Valley Traction Co., were as follows:

**Engineering-Contracting*, March 11, 1908.

There were 5,022 lin. ft. of single track made up as follows:

Main line, lin. ft.	4,481
Sidings, lin. ft.	476
Two left-hand turnouts, lin. ft.	65
Total track, lin ft.	5,022

There were 3,970 sq. yds. of repaving made up as follows:

In gage of main track, sq. yds.	3,399.1
On sidings, sq. yds.	453.9
1-ft. strip outside of rails, sq. yds.	1,117.0
Total paving, sq. yds.	3,970.0

The excavation consisted of a trench some 8 ft. wide and from 1 to 3½ ft. deep. All excavated material was hauled away, teams costing 40 cts. per hour and common labor 16½ cts. per hour. The cost of excavation was as follows:

Excavating and hauling away	$3,378.03
1 new road plow	25.00
Total cost	$3,403.03

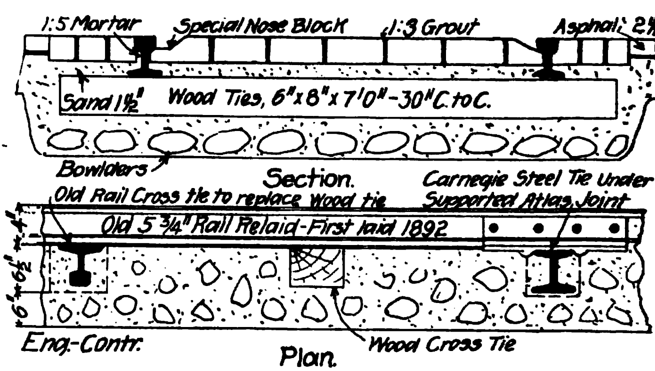


Fig. 13.—Street Railway Track.

This gives a cost for excavation of 67.7 cts. per lin. ft. of track.

The track was laid with old 5¾-in. rails, which were reversed end for end. The ties were spaced 30 ins. on centers. Altogether 4,957 ft. of track were laid, costing as follows:

Item.	Total.	Per lin. ft.
Labor	$ 784.81	$0.158
Ties	1,204.80	0.242
18 kegs spikes at $5	90.00	0.018
8 kegs bolts at $5.85	46.85	0.009
350 bonds at 60 cts.	210.00	0.041
Totals	$2,336.46	$0.468

The concrete work comprised the making and laying of 1,260 cu. yds. of concrete at the following cost:

Item.	Total.	Per cu. yd.
Stone at $1.25 per cu. yd..........	$ 973.55	$0.772
688 cu. yds. gravel and sand at $1	688.00	0.546
759½ bbls. cement at $2...........	1,519.00	1.205
Labor	527.68	0.418
Totals	$3,708.23	$2.941

This low cost of concrete per cubic yard was made possible by the use of cobble stones from the old cobble pavement in the concrete. It was estimated by the engineer that had broken stone concrete been used throughout the cost would have been $5.50 per cu. yd., so that a saving of nearly one-half was affected by using the rubble concrete. The cost of the concrete per lineal foot of track was $3,708.23 ÷ 4,957 ft. = 74.8 cts.

There were 3,970 sq. yds. of repaving which cost as follows:

Item.	Total.	Per sq. yd.
Gravel and sand..................	$ 344.20	$0.086
90½ bbls. cement at $2...........	181.00	0.046
33,145 new brick at $22.50 per M...	746.86	0.188
123,618 blocks at $18.25 per M.....	2,256.86	0.568
Unloading and hauling brick......	250.00	0.063
1 road roller....................	200.00	0.050
Labor	425.70	0.107
Totals	$4,404.62	$1.108

The cost of paving per lineal foot of track was 88.8 cts. and the total cost of the work per lineal foot of track was:

	Per lin. ft.
Excavation	$0.677
Track laying.............................	0.468
Concrete	0.748
Paving	0.888
Total	$2.781

This does not include the cost of the rails.

Comparative Cost of Street Railway Track Built with Steel and with Wood Ties.*—A steel tie laid in concrete is cheaper than a wood tie laid in concrete or broken stone in street railway track construction, according to figures by Mr. C. H. Clark, Cleveland Electric Ry., Cleveland, O. Comparison is made between the standard construction with Carnegie steel ties on the Cleveland Electric Ry., and various standard forms of construction with wood ties.

The Carnegie tie is a steel I-beam 5½ ins. deep with a top flange 4½ ins. wide and a bottom flange 8 ins. wide. The ties are spaced 6 ft. apart on centers. A strip of 1:3:6 concrete about 2 ft. wide and 5½ ins. thick is placed under each tie and the space between ties is filled with a 5½-in. layer of concrete. The

***Engineering-Contracting*, Nov. 7, 1906.

rods connecting the rails come over each tie. The actual cost of this construction per 100 ft. is given as follows:

	Per 100 ft.
16⅔ ties at $2.50	$ 41.66
17 cu. yds. concrete at $5	85.00
Total	$126.66
Total per foot of track	1.27

Using oak ties costing 80 cts. each and spaced 2 ft. on centers the cost of the several standard constructions per foot are giver as follows:

No. 1.—Tamping with material taken out; no extra excavation:

	Per ft.
Tamping	$0.04
Tie	.40
Total per ft.	$0.44

No. 2.—Seven inches broken stone under ties and concrete between the ties:

0.18 cu. yds. crushed stone, at $1.50	$0.27
1 cu. yd. concrete, at $5	.50
Tamping crushed stone	.08
Extra excavation and removing the same	.07
Tie	.40
Total per ft.	$1.32

No. 3.—Seven inches broken stone under ties and broken stone between the ties:

0.28 cu. yd. of stone, at $1.50	$0.42
Tamping the same	.08
Extra excavation and removing the same	.08
Tie	.40
Total per ft.	$0.98

No. 4.—All concrete; 5 in. below and filled to the top of the tie:

0.218 cu. yd. of concrete, at $5	$1.19
Extra excavation and removing the same	.07
Tie	.40
Total per ft.	$1.56

No. 5.—Four inches concrete; 1 in. sand under tie and concrete between the ties:

0.208 cu. yd. concrete, at $5	$1.04
Extra excavation and removing the same	.07
Tie	.40
Total per ft.	$1.51

It will be seen that the steel tie construction is cheaper in first cost than any of the concrete constructions with wood ties. Referring to this comparison Mr. Clark says:

"This is on the assumption that white oak ties cost 80 cts. apiece. This price, of course, varies in different localities, and the difference in price can readily be applied for comparison. The life of the steel tie can readily be placed at 20 years, and the white oak at about 12 years.

Cost of Welding Rails by the Thermit Process.*—The following account of the methods and cost of welding a large number of rail joints by the thermit process has been obtained from Mr. M. J. French, Engineer Maintenance of Way of the Utica & Mohawk Valley Electric Railway. A part of this information appeared originally in a paper by Mr. French, read before the Street Railway Association of the State of New York, and the remainder, covering practically all of the matter on costs, was obtained from the author by the editors of *Engineering-Contracting.* Both the methods described and the costs given refer to work on the railway named above during 1905-6.

Thermit Process.—The process of welding consists in pouring molten mild steel from a melting crucible into sand and flour molds placed around the rails at the joint. It is in detail as follows:

The rails having first been lined and surfaced, the joint is thoroughly cleaned with a sand blast or wire brush. Then the rails are heated by a gasoline or oil blow-torch to expel all moisture, and by heating the rails to a dull red better results are secured as the temperature of the molten steel is not reduced as much when coming into contact with the rails. After the joint is cleaned and heated a pair of molds made of an equal mixture of common clay and sand, or, preferably, of sand and 10 per cent of cheap rye flour, is clamped firmly to the rails. The molds are held by a wrought iron frame-work provided with handles to facilitate carrying. The molds being in place, the rail head is painted with a watery solution of red clay which the heated metal immediately dries up to a thin coating, the purpose of which is to prevent the molten slag or steel from uniting with or burning the rail head. After thoroughly luting all joints of the molds with clay of the consistency of putty, earth is packed around the outside of the molds. The molds and the rails are then given a final warming with the blow-torch, the flame being directed inside the molds to expel any remaining moisture. The crucible on its tripod is then set over the mold with its pouring hole directly over and about 2 ins. above the gate in the mold. After placing the tapping pin, iron disc, asbestos disc and refractory sand in the bottom of the crucible to act as a plug for the opening the thermit compound is poured in and in the center of the top is placed about one-third teaspoonful of ignition powder. A storm match starts the chemical process.

The thermit compound is composed of aluminum and iron oxide both in granular or flake form; the ignition powder is composed of aluminum and barium peroxide in much finer form. When the match is applied the barium peroxide ignites and releases its oxygen to the aluminum very quickly. The heat produced is so intense that it causes the iron oxide to release its oxygen, which in turn is seized by the aluminum and almost instantly the entire contents of the crucible are a boiling and seething mass. By this reaction the pure steel is liberated and settles immediately to the

---

**Engineering-Contracting,* Feb. 13, 1907.

bottom of the mold. The crucible is then tapped by striking the tapping pin with a special iron spade and the molten steel runs into the mold followed by the aluminum oxide and corundum slag. The chemical reaction described is completed in about 30 seconds, and in five minutes the molds can be removed.

Molds.—The molds are made by baking a mixture of sand and rye flour shaped on models. At first a mixture of one part clay and one part sand was used, but it resulted unsatisfactorily. The molds shrunk and checked badly in baking and required a great amount of careful luting to close the joints. Also the clay was baked like a brick by the great heat of the welded joint and was quite difficult to remove, adding somewhat to the expense. At the suggestion of an old foundryman trial was made of a mixture of clean, sharp sand, with 10 per cent of coarse rye flour; the mixture was moistened just enough to retain its form when pressed in the hand. This mixture proved satisfactory. It came away from the model without adhering, baked without shrinking and was hard enough to stand ordinary handling. By adding a teaspoonful of linseed oil to the mixture for a pair of molds it baked as hard as concrete—unnecessarily hard for ordinary purposes, but most desirable for special molds for broken or combination joints.

The molds are baked in a brick oven having a flat iron plate above the firebox to baffle the heat and above this two racks capable of holding twelve sets of molds. For baking a moderate heat, about the temperature required for making bread—has proved the most satisfactory; a higher temperature burned the rye flour and destroyed its cementing properties. One man receiving 15 cts. per hour makes and takes the molds and he can turn out 12 sets every five hours, or 24 sets per day. This gives a cost for labor of about 6¼ cts. per set. The molds actually cost about 10 cts. a set, counting in materials and lost time due to the full output of the oven not being required each day.

Crucibles.—The crucibles furnished by the Goldschmidt Thermit Co. cost $7.25 each, but since using up the first six bought the railway company has made its own, buying magnesia tar from the Goldschmidt Thermit Co. at 2½ cts. per pound. The tar is mixed with 25 per cent of old crucible material finely powdered. These crucibles last on an average for about 30 joints. They are baked in the oven previously described with a higher temperature than that required for the molds. The cost of the crucibles is $2.40 each, made up of the following items:

48 lbs. magnesia tin at 2½ cts.	$1.20
12 lbs. old crucible powder, labor	0.15
6 hrs.' labor at 15 cts., molding and baking	0.90
Fuel	0.15
Total	$2.40

Cost of Welding.—The welding was done by a gang of 1 foreman and 3 laborers. This gang has never exceeded 20 welds per 10-hour day. The wages paid were: Foreman, $2.50 per day, and laborers, $1.50 per day. The welding portion consists of 16 lbs.

thermit and 2 lbs. iron punchings, or 15 lbs. thermit and 3 lbs. iron punchings, if a lower temperature seems desirable. The total cost of the welding portion, including igniting powder, tapping pin, and plugging materials for crucible, consisting of asbestos washer, iron disc and refractory sand, is $4.25. The cost of welding 100 joints on T-rail 7 ins. high, 6 ins. base and 3 ins. head during 1906 was per joint as follows:

Cost of mold	$0.10
Cost of crucible	0.10
Cost of casting materials	0.20
Foreman	0.25
Laborers	0.91
Thermit portion	4.25
Total	$5.81

To this is to be added $1.63, which is about the average cost of removing and replacing brick pavement at each joint for labor and materials, using old broken stone for concrete and cleaning old paving blocks. This addition brings the total up to $7.44 per joint welded. The cost of welding 600 joints in 1905 on 9-in. tram head rail, including all labor, materials, tools and patterns incident to the work, experimenting with mold materials and cost of oven, was $5.86. The cost of the original outfit for welding was:

1 automatic crucible	$ 7.25
1 set mold models	12.00
1 set mold clamps	6.00
1 tapping spade	1.00
1 tripod for crucible	4.00
1 set mold boxes	2.50
Total	$32.75

Precautions.—Certain precautions are necessary to get the best results by the thermit process, and some of these we quote from Mr. French's paper as follows:

"When we began welding this 7-in. rail we found that we could sledge off the welds and that the iron from the thermit compound had not united with the rail; also that the iron came up to the top of the rail head. We subsequently found that the mold models had become mixed, and we had used one of too small horizontal cross-section, and consequently the rail chilled the small volume of molten iron coming in contact with it. Upon enlarging the mold model so that the thermit portion furnished only enough iron to come up under the rail head, we obtained welds that resisted the most vigorous sledging that could be given with a 10-pound hammer. We were able to batter the weld out of shape, but could not separate it from the rail. This sledging test is now applied to all welds.

"We found when welding in the morning with rising temperature that tightly-closed joints often humped up when welded. This proved to be due to the latent compression in the rails that did not manifest itself until the rail ends became soft. These humped joints were ground down with an emery wheel grinder. We had

only a few of these joints when we realized the cause, and readily prevented such action by welding on cooler days or when the temperature was falling. We obtained the best results with joints open about 1/16 to 1/32 in., the expansion in welding closing tightly such an opening. We have made excellent combination welds between 80-lb. T-rail, 7-in. 70-lb. and 95-lb. T-rails and 9-in. girder rails. In making combination welds we found that it was essential to get a good body of metal between the upper side of the base of the deeper rail and the under side of the shallower section in order to secure the strongest type of weld.

"Thus far there has been no appreciable excess wear in the head of the rails at the welds and the heated portion seems to take the original temper, as it cools down slowly in about the same way as when coming from the rolls.

"A few portions of thermit, not over six, have been lost through failure of the workman to tap the crucible properly, or lack of luting around the joints of the molds. We have had but one explosion during our entire experience. That occurred after using the process 18 months, and was caused through carelessness in welding on a rainy day and in not thoroughly luting the molds near the top. The slag came in contact with the wet earth around the mold, but aside from the scare occasioned by the report and a slight burn on the foreman's arm from flying slag no harm was done, and the weld turned out to be a good one."

Cost of Electrically Welding 3,087 Rail Joints.*—Mr. P. Ney Wilson gives the following:

There are many miles of perfectly welded track in existence, and this fact seems sufficient to prove that the process is not a failure; for the successfully welded track, aside from the question of theoretical points in the process, furnishes abundant proof that with proper attention the weld is efficient and the nearest approach to the perfect joint that track engineers have yet seen.

The one important and serious drawback to the use of the weld was the inclination towards undue crystallization, caused by the sudden application of severe heat. This condition developed during the experimental stage and seems to have been obviated by the more scientific application of the process.

In the case of old track with more or less battered joints, prices should be obtained upon a step joint for raising the receiving rail sufficiently to surface the lowest spot on the dish with the abutting rail. To this figure should be added the cost of the bonds (loose and battered joints are usually accompanied with inefficient bonding); then add labor cost and incidental material and make a total. This total should be compared with the cost of welding, and, after considering the increased life due to welding, a decision based upon facts can be made.

To illustrate the point just made an example is chosen from work done at Camden, N. J., in the fall of 1905 on the lines of the South Jersey Division of the Public Service Corporation.

**Engineering-Contracting*, Mar. 20, 1907.

Organization of the Work.

The organization of the gang doing the work, as shown in the detailed statement, consisted of about 100 men, 75 of whom worked on the day shift and the balance of 25 on the night shift. It was found that it was not necessary to have more than 25 men working at night, as the day gang could keep ahead of the welding machine with very satisfactory results. The figures showing the average number of men in gang per day are based upon a ten-hour day at 15 cts. per hour, assuming that all the men received the same rate. This figure is shown in this way so that it can be applied in any locality where a higher or lower rate of wages is paid; for instance, the average number of men per day required on the entire operation was 97.6. This figure being arrived at, assuming that all of the men and teams worked at the same rate per hour, would effect, of course, the cost per joint labor for opening, closing, shimming and aligning, etc., in other localities; this latter cost being increased or decreased in proportion to the increase or decrease in the rate per hour, as the case may be.

The operation in Camden was handled by four foremen, two sub-foremen and on an average of three teams per day. The rate paid the foremen was 25 cts. per hour; rate for teams, 45 cts. per hour, and rate of men in the gang, 15 cts. per hour. It might be added that in the gang doing the work there was about 50 per cent of first-class track laborers at the 15-ct. rate. These men were experienced trackmen and the low cost per joint bears evidence of their capability.

The actual welding of the joints was done by the Lorain Steel Co. on contract at $5.25 per joint. This price is governed, of course, by the number of joints covered by contract. They agree to pay to the railway company $10 to $12 per joint for every joint that breaks within one year from date of welding. The breakage for the first year was 1 per cent, the cost of cutting in new rails being covered by the rebate from the contractor. The track having been already subjected to all seasons of the year, we now assume that the breakage will be materially decreased until the rail is worn to a point where it should be relaid. Very little new material was used by the railway company, it consisting of iron shims, sand, oil for red lights, hacksaw blades and other inexpensive miscellaneous track material. It was not necessary to mix concrete for filling in holes for paving foundation, for in the above case the city was under contract with a paving company, who followed up the welding machines and replaced asphalt on Broadway and on Kaighn Ave. The paving on all other streets was placed by the railway company, using the men in the gang at the rate mentioned. The aligning, surfacing and shimming of the joints was done by six skilled trackmen under a foreman. These men were trained especially for joint repairs with the idea in view that too much care cannot be taken in bringing the joint to proper alignment and surface.

An important feature in the maintenance of way man is the obtaining of proper credit for old material, which has been returned to scrap or to stores, it being manifest that in case of welding rails that the bonds and the joints taken off should be credited to the operation.

Cost of Work.

Haddonfield Pike.—The work on this street comprised the welding of the joints in both tracks of a double track line. Altogether 989 joints were welded in 7-in. girder rail of Pennsylvania Steel Co.'s section No. 238 and Cambria section No. 824. The rails were 60 ft. long. The pavement was Belgian blocks on sand. The work was started on Sept. 23, 1905, and was finished on Oct. 6, 1905, making 14 days' work. The average number of men in the gang per day, based upon a 10-hour day at 15 cts. per hour, inclusive of Sundays and rainy days, was 103.7. The price received for scrap fish plates was $15.60 per gross ton and for copper bonds was 15½ cts. per lb. The cost of the work was as follows:

Cost of Fitting Joints for Welding:	Total.	Per joint.
103.7 men 14 days at $1.50	$2,177.55	$2.201
Cost of material	140.85	0.142
Total	$2,318.40	$2.343
Credit for scrap	900.00	0.910
Cost after deducting credit	$1,418.40	$1.433

We have, then, the cost of welding per joint as follows:

Cost of fitting joint for welding	$1.433
Contract price for welding	5.25
Total	$6.683

This figure gives a cost per mile as follows:

For 30-ft. lengths	$2,352.76
For 60-ft. lengths	1,176.38

State Street.—The work on this street comprised the welding of 191 joints on 7-in. girder rail Cambria section No. 834. For 115 joints the rails were 30 ft. long, and for 76 joints they were 60 ft. long. The pavement was Belgian blocks on sand. For the scrapped fish plates the company received $15.60 per gross ton, and for the copper bonds 15½ cts. per lb. The average number of men in the gang per day, based upon a 10-hour day and 15 cts. per hour, was 84.6. Work was started on Oct. 13, and finished on Oct. 16, 1895, and occupied three working days, making the average number of joints finished per day 63.6. The cost of the work was as follows:

Cost of Fitting Joints for Welding:	Total.	Per joint.
84.6 men 3 days at $1.50	$280.56	$1.993
Cost of material	57.61	0.201
Total	$458.17	$2.294
Credit for scrap	174.26	0.912
Cost after deducting credit	$283.91	$1.382

We have, then, the cost of welding per joint as follows:

Cost of fitting joint for welding	$1.382
Contract price for welding	5.25
Total	$6.632

These figures give a cost per mile as follows:

For 30-ft. lengths	$2,334.46
For 60-ft. lengths	1,167.23

Broadway and Kaign Avenue.—This job comprised the welding of 715 joints on double-track line on Broadway, and of 64 joints on one-track on Kaign Ave., making a total of 779 joints. The rail in both cases was 7-in. girder Pennsylvania Steel Co., section No. 238. The pavement on Broadway was asphalt between rails, and part of shoulder and Belgian blocks along rails, on 6 ins. of concrete. On Kaign Ave. the pavement was bricks between rails and on shoulder and asphalt, both on 6 ins. of concrete. The rails in both cases were 30 ft. long. For the scrapped fish plates the company got $15.60 per gross ton, and for the old copper rail bonds 15½ cts. per lb. The average number of men worked per day, based upon a 10-hour day at 15 cts. per hour, inclusive of Sundays and rainy days, was 99.7. The work was done in September and October, 1905, and lasted 13 days, so that the average number of joints finished per day was 60. The cost of the work was as follows:

Cost of Fitting Joints for Welding:	Total.	Per joint.
99.7 men 13 days at $1.50	$1,944.94	$2.496
Cost of materials	239.78	0.307
Total	$2,184.72	$2.803
Credit for scrap	712.14	0.914
Cost after deducting credit	$1,472.58	$1.889

The work required replacing 1016.6 sq. yds. of asphalt at a total cost of $2,569.65, or $2.527 per sq. yd. As there were 779 joints the repairs amounted to 1.305 sq. yds. per joint, and cost $3.298 per joint. We then have the total cost of welding per joint as follows:

Fitting joint for welding	$1.889
Contract price for welding	5.25
Repairs to pavement	3.298
Total	$10.437

These figures give a cost per mile as follows:

For 30-ft. lengths	$8,131.97
For 60-ft. lengths	1,837.08

Moorestown Pike.—The work on this job comprised the welding of 1,128 joints on double track laid with 60-ft. 9-in. and 7-in. girder rail Pennsylvania Steel Co.'s sections No. 238 and No. 200. The pavement was Belgian blocks on sand. Scrap fish plates fetched $15.60 per gross ton, and scrap bands 15½ cts. per lb. Work was started Oct. 16 and was finished Nov. 5, 1905, thus lasting 18 days. The average number of men worked per day, based on a 10-hour

day at 15 cts. per hour, inclusive of Sundays, and rainy days, was 93.6. The average number of joints welded per day was 62.6. The cost of the work was as follows:

Cost of Fitting Joints for Welding:	Total.	Per joint.
93.6 men 18 days at $1.50	$2,628.19	$2.241
Cost of material	142.85	0.127
Total	$2,671.04	$2.368
Credit for scrap	1,030.19	0.913
Cost after deducting credit	$1,640.85	$1.455

We then have the total cost of welding per joint as follows:

Fitting joints for welding	$1.455
Contract price for welding	5.25
Total	$6.705

These figures give a cost per mile as follows:

For 30-ft. lengths	$2,359.80
For 60-ft. lengths	1,179.90

Total Work.—Summarizing the above figures we have a record of which gives us the following:

Number of days worked	48
Number of joints welded	3,087
Number of joints welded per day	64.3
Average number men worked	97.6

Cost of Work:	Total.	Per joint.
Labor preparing joints	$ 7,031.24	$2.277
Materials preparing joints	581.09	0.188
Total	$ 7,612.33	$2.465
Credit for scrap	2,816.59	0.912
Cost after deducting credit	$ 4,795.74	$1.533
Cost replac. 1,016.6 sq. yds. asphalt	2,589.65	0.832
Contract price for welding	16,206.75	5.25
Totals	$23,572.14	$7.635

These figures give us a cost per mile as follows:

For 30-ft. rails	$2,687.52
For 60-ft. rails	1,343.75

Discussion of Results.

The first cost per joint, represents cost in labor and material to the railway company exclusive of the contract price for doing the welding. The average number of finished joints per day on the above operation was 64. It should be understood that this figure is arrived at by dividing the total number of joints by the total days, inclusive of Sundays and rainy days and loss of time, due to the moving of the machine from one street to the other. Under favorable conditions 80 joints per day of 24 hours can be opened, welded, repaved and left in finished condition.

In paved streets the question of expansion and contraction need be the cause of any worry on the part of the engineer, as

there being little change in the temperature of the earth, there is correspondingly very slight expansion and contraction. Slip joints in closed streets are not satisfactory, and after practical experience are not being advocated, for the reason that it is practically impossible to calculate where the contraction strain will take place.

It was assumed that the rail welded would have to be relaid in four years, owing to battered joints, and from the fact that Broadway and Kaign Ave. was laid in concrete with asphalt paving and would cost for relaying $5 per foot for paving alone, figures showed conclusively that a saving could be effected and the life of the rail increased from 75 to 100 per cent. On Haddonfield and Moorstown Pike the cost per joint per year for keeping them in a fair condition was 90 cts. This included opening and closing joint, placing new plates and shimming.

Taking into consideration the above figures and excessive cost of re-construction on Kaign Ave. and Broadway, it was evident that saving could be made by welding joints. One per cent of breakage was a small matter in comparison to the increasing bad condition of all of the joints. On Broadway and on Kaign Ave. with a total of 779 welded joints there were none broken. These two streets were paved with asphalt on concrete. The entire number of broken joints occurred on Haddonfield Pike and Moorstown Pike, where the track was laid on sand and paved roughly with rubblestone. To the condition of the paving was attributed the breakage, as in the winter months the snow and ice had an opportunity to get around the rail, reducing the temperature of the rail to such an extent that breakage followed.

The Lorain Steel Co. has recently successfully applied the process to T-rail track on interurban lines, having welded a stretch of about six miles from Providence, R. I., to River Point. In this track they used expansion joints every 1,000 ft.

Cost of Erecting Trolley Poles.—A gang of 4 men digging holes and 6 men raising poles averaged 36 poles set per 10-hr. day, or 50 cts. per pole at this rate, and with wages at $1.80 per day, a man digs 9 holes per day at a cost of 20 cts. per hole, and a man raises 6 poles per day at a cost of 30 cts. per pole.

In digging holes 24 ins. diam. and 5 ft. deep for telegraph poles, using a crowbar and "spoon" shovel, a man will dig only 3 holes a day in stiff clay, and 7 holes in average earth.

Cost of Reinforced Concrete Trolley and Transmission Line Poles.*—The Fort Wayne and Wabash Valley Traction Co. has made reinforced concrete trolley poles and transmission line poles, the cost of which was as follows in 1906:

The trolley poles are 32 ft. long, 8 ft. of which is below the ground level. The pole is 10 ins. square at the ground level and 6 ins. at the top, and is reinforced with 8 twisted steel rods, ⅜ in. It contains 22½ cu. ft. of 1 ÷ 3 ÷ 3 gravel concrete, and 122 lbs. of steel, weighs 3,300 lbs., and costs $7.50 at the gravel pit. The transmission pole is 42 ft. long, 8 ft. being underground. It is 12

*_Engineering-Contracting_, July 14, 1909.

ins. square at the ground level, and 6 ins. at the top, and is reinforced with 8 twisted steel bars (½ in.), 4 of which are 32 ft. long and 4 are 42 ft. long. It contains 29 cu. ft. concrete, 242 lbs. reinforcing bars and 21 lbs. of steps, weighs 4,400 lbs. and costs $13.

First Cost and Cost of Operating a Trolley Line—"Street Railways," by C. B. Fairchild, contains the following estimate, made in 1892, of the cost of constructing, equipping and operating 3 miles of double track electric trolley line, with power station near the center of the line.

	Total.	Per mile of single track.
Road Bed:		
15,840 lin. ft. stone ballast (6 ins. below ties and between ties), including excavation for same, at $0.90	$ 14,256	$ 2,376
15,136 ties (5 x 7-in.) at $0.45	6,811	1,135
1,056 double joint ties at $0.75	792	132
31,680 ft. rails (78-lb.), including all other iron and steel at $1.42	44,986	7,498
6 miles electrical construction, including copper return wire, at $500.00	3,000	500
31,680 ft. track laying (labor, teaming and supt.) at $0.30	9,504	1,584
28,158 sq. yds. granite pavement at $3.00	84,474	14,079
Total road bed	$163,823	$27,304
Special Street Construction:		
2 cross-over switches at $525.00	$ 1,050	$ 175
1 double track crossing	270	45
180 degs. double track curve	492	82
Total special street construction	$ 1,812	$ 302
Overhead Street Construction:		
270 iron pipe poles (6 x 5 x 4 ins. x 28 ft.) and fittings at $26.00	$ 7,020	$ 1,170
8 iron terminal and curve poles at $50.00	400	67
278 poles set with concrete foundations at $7.00	1,946	324
278 poles painted at $1.00	278	46
10,224 lbs. (No. 0) trolley wire at $0.15	1,534	256
2,200 lbs. (5/16, 7 strand) galvanized steel wire (50 ft. street) at $0.055	121	20
15,600 lbs. feed wire (4 miles) at $0.17	2,652	442
270 lbs. strain and anchor wire at $0.04	11	2
3 miles line and insulating appliances, lighting arresters, etc., at $300.00	900	150
3 miles labor stretching trolley and feed wire and attaching insulating appliances, at $500.00	1,500	250
Total overhead construction	$ 16,361	$ 2,727
Special Overhead Construction:		
6 trolley switches at $3.00	$ 18	$ 3
2 double track curves (90 deg.) at $75.00	150	25
Guard wire and guard span half the line, with connections	250	42
Total special overhead construction	$ 418	$ 70

Power House and Plant:

Real estate	$ 10,000	$ 1,667
House, 100 x 175 ft.	25,000	4,166
Steam plant, 1,050 hp. (35 hp. per car) (2 slow speed engines, boilers, etc.), at $65.00	68,250	11,375
Electrical equipment (including generators, switchboard, etc.), 900 hp. (30 hp. per car) at $35.00	31,500	5,250
Total power house and plant	$134,750	$22,458

Rolling Stock and Equipment:

15 motor car bodies (16-ft.) at $1,000.00	$ 15,000	$ 2,500
15 motor trucks at $275.00	4,125	687
30 motors (20 hp.) and electrical appliances, at $1,250.00	37,500	6,250
15 coaches (trailers) with trucks at $1,200.00	18,000	3,000
Total rolling stock	$ 74,625	$12,437

Car Barn and Repair Shop:

Real estate	$ 2,500	$ 416
Car house, fireproof	25,000	4,167
Pits, tracks and switches	4,000	667
Repair shop equipment	8,500	1,417
Total car barn and repair shop	$ 40,000	$ 6,667

Auxiliary Appliances:

1 electric snow plow and sweeper	$ 5,000	$ 833
Other snow appliances	1,000	167
1 wrecking wagon, tools and team	800	133
1 high wagon, tools and horse	600	100
1 express wagon and horse	350	58
1 heavy wagon and team	500	83
2 carts	100	17
Track tools, etc.	300	50
Total auxiliary appliance	$ 8,650	$ 1,442
Grand total	455,439	75,906

I give the foregoing estimate principally as an illustration of an extravagantly expensive line, and one to which the estimator has applied the highest possible unit prices in nearly every item. It is by no means typical.

Mr. Fairchild gives the following estimate of cost of operating 15 trains (motor and trail car), running on 4 mins. headway, including an allowance for "depreciation." He figures the life of the destructible part of the plant at 20 years, and provides a sinking fund that at 3% compound interest will redeem the plant in 20 years. This amounts to $13,870 per year, or $38 per day, which shows that he figured this depreciation on a plant of about $365,000.

	Per day.
Depreciation of plant and rolling stock	$ 38.00
Repairs, engines, boilers, generators, etc.	13.00
Repairs, cars (including motors)	78.00
Repairs, track, overhead construction and bldgs.	47.00
Track cleaning, train and shop expense	14.00
Track service	8.00
Power and car house expenses	6.00
Car house service, inclusive of cleaning, inspection, etc.	20.00
Engineers, fireman and dynamo tenders	25.00
66 motormen and conductors at $2.00	132.00
12 tons (2,240 lbs.) coal at $2.50	30.00
Water, oil and grease	10.00
Injury to persons and property	10.00
Legal, secret service and insurance	8.00
Licenses and taxes	7.00
General and miscellaneous expense	32.50
Total operating expense	$478.50

Each of the 15 trains will make 110 miles per day, or 1,650 train miles, or 3,300 car miles per day for the line. Hence, dividing $478.50 by 3,300 gives 14½ cts. per car mile.

The repairs to the power plant machinery, $13 daily, amount to $4,745 per year, or less than 5% on the first cost, which is altogether too low.

The repairs to cars, $78 daily, amount to $28,470 per year, or more than 38% of the first cost, which is ridiculously high.

The repairs to track, overhead construction and buildings, $47 daily, amount to $17,155 per year. Excluding the ballast and pavement, the track materials and labor cost about $65,000, the overhead construction cost $16,000; the buildings cost $50,000; total $131,000. Hence, the $17,155 repairs is more than 13%; but iron poles, fireproof buildings and durable construction are provided throughout (except the ties). Hence, this item is inordinately high.

In brief, not a single item of repairs is correctly figured, and the most important items are wide of the truth. Errors of the kind made by Mr. Fairchild are best detected by expressing the annual costs of repairs as a percentage of the first cost.

Estimated First Cost and Cost of Operating a 4-Track Electric Railway.—"Electric Railway Economics" (1903), by W. C. Gottschall, contains the following estimate of the maximum cost of suburban electric railway.

	Per mile single track.
Rails (80-lb.), $33 per ton deliv., and fastenings	$ 5,100
Labor laying track	900
Track bonding	750
2,640 white oak ties (6 x 8 ins. x 8 ft.) at $0.70	1,848
2,750 cu. yds. rock ballast at $1.50	4,125
20,000 cu. yds. grading at $0.30	6,000
Third rail	7,000
Copper and installation thereof	2,500
Bridges and culverts	12,000
Labor and incidentals	400
Power stations at $100 per kw.; sub-stations at $40 per kw.	18,000
Rolling stock (5 min. headway)	8,000
Real estate and right of way	20,000
Incidentals, including block-signals, telephones, fencing, etc.	4,000
Total	$90,623

Mr. Gottschall gives an estimate of the probable cost of operating a 4-track interurban road, 24 miles long (New York & Port Chester), as follows:

96 miles of main single track.

124 daily local trains each way, trains of 1 car.

74 daily express trains each way, trains of 2 cars.

4,500,000 car miles per annum.

248 daily local trains both ways, 49 mins. each.

148 daily express trains both ways, 31 mins. each.

Hence:

248 × 49 ÷ 60 = 202.5 car hours per day of local train service.

	Per car hr.
1 motorman at	$0.30
1 conductor at	0.25
Total	$0.55

202.5 car hrs. × $0.55 × 365 days = $40,752 per year.

In like manner for express trains:

2 × 148 × 31 ÷ 60 = 152.8 car hrs. per day.

	Per train hr.
1 motorman at	$0.30
1 conductor at	0.25
Total	$0.80

This is equivalent to $0.40 per car hr. 152.8 car hrs. × $0.40 × 365 = $22,309 per year.

Train Crews:	Per year.
Train crews, local trains	$40,752
Train crews, express trains	22,309
Total	$63,061
Add ⅓ for extra man	21,020
Grand total train crews	$84,081

Station Crews:

22 stations using 5 men = 110 men.

110 men × $2.00 × 365 days = $80,300 yearly.

Maintenance of Equipment:

4,169,760 car miles plus allowance for extra occasions = 4,500,000 car miles.

4,500,000 at $0.02 = $90,000 yearly.

Maintenance of Roadway and Structures:		Per mile per yr.
5% of $5,092, first cost of rails and fastenings		$ 254
6% of $1,848, first cost of oak ties (at $0.70 ea.)		108
5% of $2,700, first cost of rock ballast		135
Labor of section and line men:		
5 trackmen at $1.80	$ 9.00	
2 linemen at $2.50	5.00	
Total per day for 12 miles	$14.00	
$14 ÷ 12 × 312 days =		364
Repairs and renewals of fences		25
Total		$ 886
Add for contingencies, etc.		114
Grand total maintenance roadway		$ 1,000
96 miles at $1,000 yearly		96,000

Electric Power:

Weight of loaded motor car is estimated to be:

	Tons.
Car and trucks	25
Electric equipment	17
Total	42
Passengers	10
Total when loaded	52

With 5,208 local car miles daily, at 52 tons per car, we have 270,816 ton miles. At 160 watt hours per ton mile (see Table XXVa) we have: 160 × 270,816 = 43,330,560 watt hours per day for local service. In similar manner we get 42,020,160 watt hours per day for express service; total 85,350,720 watt hours per 24 hr. day, or 85,351 kw. hours.

Add:	Per cent.
Transmission loss from main station to 3d rail	18
Heating cars	5
Lighting cars, etc	2
Total to be added	25

We have 85,351 + 21,338 = 106,689 kw. hrs. per 24-hr. day, or a plant of 4,445 kw.

The cost per kw. hr. was estimated thus:

Power Station Labor:	Per day.
1 chief engineer	$ 10.00
3 assistant engineers at $5.00	15.00
30 oilers at $2.50	75.00
3 switchboard men at $3.50	10.50
3 electric helpers at $2.50	7.50
6 cleaners at $1.50	9.00
6 condenser men at $2.50	15.00
1 machinist and 2 helpers	9.00
24 boiler men at $2.50	60.00
1 boiler cleaner and 2 helpers	6.00
4 laborers at $1.50	6.00
Total labor per day	$ 223.00
Total labor per year	$ 81,395.00
Fuel:	
106,684 kw. at 2¾ lbs. coal = 293,381 lbs.; therefore, 146.69 tons coal at $2.40	$ 352.06
Total labor and fuel per day	$ 575.06
Total labor and fuel per year	209,897.00
Hence:	Per kw. hr.
$575 ÷ 106.684 =	$0.00538
Add for repairs, etc	0.00112
Total	$0.00650

This allowance of $0.00112 per kw. for repairs of power station is equivalent to $119.50 per day, or $42,718 per year. Since a power station and sub-station would not cost more than $140 per kw., the

total cost of power plant would be \$633,300 for a 4,445 kw. plant. Hence the \$42,718 repairs per year is about 7% of the first cost.

The allowance of 2 cts. per car mile for maintenance of equipment is far too low for large high speed electric cars (42-ton). He should have taken fully 10% of the first cost of each car, for annual repairs, and that divided by the annual car miles would have given the cost of repairs per car mile.

The allowance of 5% per year for renewals of rails is excessive. Mr. Gottschall errs seriously in this. He reasons as follows:

The life rails for main line service of steam railway trunk lines is 15 years; but such a service is equivalent to 20 years on a high speed electric line where heavy locomotives are not used. Hence, a life of 20 years, or 5% depreciation, for rails in an electric line is assumed. Mr. Gottschall fails to consider that when a rail is removed from a main line it has a scrap value of about half its first cost. This being so, it has depreciated only 2½% per year, instead of the 5% assumed by Mr. Gottschall.

On the other hand, the 6% depreciation that he assumes for white oak ties is too low. Such ties will not last more than about 10 years.

But then, on the other hand again, his assumed 5% annual depreciation of rock ballast is ridiculously high.

TABLE XXVa.—WATT HOURS PER TON MILE.

Distance between stops, miles.	Watt hrs. per ton mile for schedule speed of 40 mi. per hr.	35 mi. per hr.	30 mi. per hr.	25 mi. per hr.	20 mi. per hr.	15 mi. per hr.
3	110	80	78	65	53	40
2½	121	90	83	74	54	40
2	142	99	86	80	60	41
1½	...	123	95	85	68	43
1	...	...	128	90	74	50
½	...	...	...	145	119	56
¼	...	...	...	...	...	120
Train friction in lbs. per ton	35	30	27½	25	20	15

Note: 1. The breaking effort or retardation is taken at 150 lbs. per ton.

2. The stops are taken at 15 secs. each, except for the 15-mi. schedule, where 10 secs. are taken.

3. A schedule speed of 25 mi. will require actual speeds of 40 to 50 mi. per hr., etc.

4. The rate of acceleration for the long runs varies from 75 to 110 lbs. per ton, going as high as 210 lbs. per ton for the short runs.

5. The table applies only to single car trains. If more than one car is used, the train friction in lbs. per ton decreases, hence the electric energy required decreases.

6. The figures are for the electric energy required at the motors.

Cost of Power Plants for Electric Railways.—"Electric Railways" (1907), by Sydney W. Ashe, contains the following power plant costs estimated by Mr. H. G. Stott:

	Per kw. Min.	Per kw. Max.
1. Real estate	$ 3.00	$ 7.00
2. Excavation	0.75	1.25
3. Foundations, recipr. engines	2.00	3.00
4. Foundations, turbines	0.50	0.75
5. Iron and steel structure	8.00	10.00
6. Building	8.00	10.00
7. Floors, galleries and platforms	1.50	3.50
8. Tunnels, intake and discharge	1.40	2.80
9. Ash-storage pocket, etc.	0.70	1.50
10. Coal hoisting tower	1.20	3.00
11. Cranes	0.40	0.60
12. Coal and ash conveyors	2.00	2.75
13. Ash cars, locomotives and track	0.15	0.30
14. Coal and ash chutes, etc.	0.40	1.00
15. Water, meters, storage tanks and mains	0.50	1.00
16. Stacks	1.25	2.00
17. Boilers	9.50	11.50
18. Boiler setting	1.25	1.75
19. Stokers	1.80	2.20
20. Economizers	1.30	2.25
21. Flues, dampers and regulators	0.60	0.90
22. Forced-draught blowers and air	1.25	1.65
23. Boiler, hand and other pumps	0.40	0.75
24. Feed water heaters, etc.	0.20	0.35
25. Steam and water piping, traps, separators, high and low pressure	3.00	5.00
26. Pipe covering	0.60	1.00
27. Valves	0.60	1.00
28. Main engines, reciprocating	22.00	30.00
29. Exciter engines, reciprocating	0.40	0.70
30. Condensers, barometric or jet	1.00	2.50
31. Condensers, surface	6.00	7.50
32. Electric generators	16.00	22.00
33. Exciters	0.60	0.80
34. Steam turbine units complete	22.00	32.00
35. Rotaries, transformers, blowers, etc.	0.60	1.00
36. Switchboards, complete	3.00	3.90
37. Wiring for lights, motors, etc.	0.20	0.30
38. Oiling system, complete	0.15	0.35
39. Compressed air system, etc.	0.20	0.30
40. Painting, labor, etc.	1.25	1.75
41. Extras	2.00	2.00
42. Engineering and inspection	4.00	6.00
Total, excluding Items 4, 22, 31 and 34	$102.00	$148.00

Mr. W. C. Gottschall gives a similar estimate, as follows:

RECIPROCATING STEAM ENGINE POWER-STATION COSTS PER KILOWATT.

	Per kw. Max.	Per kw. Min.
1. Buildings	$ 15.00	$ 8.00
2. Foundations	3.50	1.50
3. Boilers and settings	17.00	9.00
4. Steam piping and covering	12.00	4.00
5. Engines	32.00	20.00
6. Generators	21.00	18.00
7. Pumps, etc.	1.00	1.00
8. Switchboards, etc.	4.00	1.50
9. Feed water heaters, etc.	2.00	1.00
10. Wiring conduits, etc.	6.00	3.00
11. Coal storage and conveyors	6.00	2.00
12. Smokestack and flues	2.00	1.00
13. Fuel economizers	4.50	2.50
14. Stokers	3.00	2.50
15. Ash conveyors	1.50	1.00
16. Incidentals	2.00	2.00
Total	$132.50	$78.00

A fair average is $100 to $110 per kw. The cost of sub-stations using rotary converters will range from $38 to $45 per kw. including the building. Land is not included in the above costs.

Cost of Power Plant and Equipment of an Electric Railway.—Mr. W. A. Blanck gives the following estimated cost (in 1904) of the electrical equipment of a 60-mile, single-track, interurban trolley railway:

Power House:	Direct current.	Alternating current.
Building	$ 10,000	$ 10,000
Foundations	2,500	2,500
Boilers and settings	12,000	12,000
Steampipe and covering	7,500	7,500
Engines	22,000	22,000
Generators, two 400 kw.	18,000	23,000
Exciters	1,000	1,000
Step-up transformers, 800 kw.	8,000	7,500
Switchboard	3,500	3,000
Wiring	3,000	2,500
Feed water heater	800	800
Pumps	800	800
Coal storage	1,000	1,000
Smokestack and flues	2,000	2,000
Fuel economizers	3,000	3,000
Stokers	3,500	3,500
Incidentals	4,400	4,400
Total power house	$103,000	$106,500
Sub-station in Power House:		
Building extension	$ 1,000	$ 600
Synchronous converter, 300 kw.	4,800	.....
Transformer, 300 kw.; 200 kw. alternating current	3,200	2,000
Switchboard	2,000	1,300
Wiring	1,000	500
Incidentals	600	200
Total sub-station	$ 12,600	$ 4,600

Transmission Line (48 Miles):		
Poles (see Trolley Line below).		
Copper	$ 10,000	$ 11,500
Insulators, pins and cross-arms	7,500	5,000
Erection	4,000	3,000
Incidentals	1,000	1,000
Total transmission line	$ 22,500	$ 20,500
Sub-stations Along Road:		
Buildings, four	$ 8,000	$ 4,000
Synchronous converters, four	19,200	
Step-down transformers	12,800	8,000
Switchboards, four	8,000	5,200
Wiring	4,000	2,000
Incidentals	2,000	800
Total 4 sub-stations	$ 54,000	$ 20,000
Trolley Line and Feeders:		
Poles, 3,500, at $5	$ 17,500	$ 17,500
Poles distributed and set	4,000	4,000
Guys and anchors	2,000	2,000
Brackets with hangers	18,000	25,000
Copper, direct current:		
Feeder, 12 miles, 500,000 circ. mils.		
Feeder, 48 miles, No. 0000.		
Trolley, 120 miles, No. 000	95,000	.....
Alternating current:		
Trolley, 60 miles, No. 00	.....	21,500
Feed insulators	2,000	.....
Erection	10,000	4,000
Incidentals	7,500	4,000
Total trolley line	$156,000	$ 78,000
Bonding of Rails:		
Both rails bonded	$ 30,000	.....
One rail bonded	.....	$ 15,000
Cross bonds	2,000	1,000
Total bonding of rails	$ 32,000	$ 16,000
Rolling Stock:		
10 vestibuled passenger cars, each with 4 motors, wt. 30 tons	$ 75,000	$ 85,000
2 express passenger cars, each with 4 motors, wt. 35 tons	18,000	20,500
2 baggage cars, each with 4 motors, wt. 30 tons	10,000	12,000
Snow plow and construction car	7,000	8,500
Total rolling stock	$110,000	$126,000
Summary:		
Power house	$103,000	$106,500
Sub-station in power house	12,600	4,600
Transmission line	22,500	20,500
Sub-stations	54,000	20,000
Trolley line and feeders	156,000	78,000
Bonding of rails	32,000	16,000
Rolling stock	110,000	126,000
Grand total	$490,100	$371,600
Cost per mile (60 miles)	$ 8,168	$ 6,193

The running schedule upon which the above is based is as follows: 5 local cars having 1-hr. headway; 1 express car, making round trip in 3 hrs.; 1 freight and baggage car, making trip between the two terminals in 8 hrs.

Cost of a Street Railway Power Plant and of its Operation.—Mr. R. W. Conant gives the following estimated cost of a street railway power plant and its cost of operation:

The plant has a capacity of 3,600 kw. There are three cross-compound condensing engines, three 1,200-kw. generators, and six water-tube boilers of 500-hp. each. The estimated cost of this plant in 1898 was:

Engines, condensers, heaters, separators and piping	$ 91,800
Feed pumps and fuel economizers	18,000
Boilers and flue connections complete	61,000
Generators and switchboard complete	73,800
Building, chimney, engine and boiler foundations, coal handling apparatus, etc.	120,000
Land	17,000
Engineering and sundries	5,000
Total	$386,600

This is equivalent to $107 per kw.

Mr. Conant estimates fixed charges at 11%, or $42,526, distributed thus:

	Per cent.
Interest	6
Insurance and taxes	3
Depreciation	2
Total	11

The item of "depreciation" is badly underestimated, for it includes current repairs.

It is assumed that this station is operated with 3 shifts of men, 8 hrs. per shift, for 8,760 shift hours per year. The crew of one shift would be:

2 enginemen.
2 firemen.
1 oiler.
1 helper.
1 coal passer.

7 men at 27 cts. per hr. = $1.89.

The plant is assumed to work with a load factor of 33⅓%, so that it actually averages 1,200 kw. for 8,760 hrs., or 10,500,000 kw. hours per annum.

Therefore, we have:

	Per kw. hour.
Fixed charges, $42,526 ÷ 10,500,000	0.40 cts.
Wages, $1.89 ÷ 1,200	0.16 cts.
Coal, 2.2 lbs., at $3 ton	0.33 cts.
General expense, super., supplies and repairs.	0.09 cts.
Total, including fixed charges	0.98 cts.

Mr. Conant states that the fuel cost would be practically doubled were non-condensing engines used, for he has assumed a steam consumption of only 14½ lbs. of steam per i. hp., a transformer effi-

ciency of 90%, and a boiler efficiency of 9.4 lbs. of steam per lb. of coal.

He calls the above a "standard plant," an ideal capable of realization, which is exceedingly doubtful, however, as the actual records of some 28 street railway power stations show.

A summary of these 28 plants gives the following average:

Average capacity, 2,140 kw.

Average load factor, 30%.

Average number men per shift, 10.

Average number shifts, 2 of 12 hrs.

Average wage, 20 cts. per hr.

The average cost of generating power was:

	Per kw. hr.
Labor, 1.5 hrs., at 20 cts.	0.30 cts.
Coal, 5 lbs., at $2.10 per ton	0.53 cts.
General expense	0.15 cts.
Total, not including fixed charges	0.98 cts.

The "load factor" of 30% means that the average output of electricity during the entire year was 30% the capacity of the plant; hence it was 30% of 2,140 = 642 kw.

There was not a single one of these 28 plants that operated with as little fuel as Mr. Conant's "ideal plant," for the most efficient plant required 3 lbs. of coal per kw. hr.

The cost of labor per kw. hr. obviously varies greatly as the "load factor" varies. In one of these plants the load factor was as high as 57%, giving a very low unit cost (0.18 ct. per kw. hr.) for labor; while in another plant the load factor was only 11%, giving an extraordinarily high unit cost (1.1 ct. per kw. hr.) for labor.

As above pointed out, Mr. Conant's estimate of his so-called "fixed charges" on the plant, is entirely too low.

Cost of Operating Street Railways.—The most satisfactory records of this sort are to be found in the annual reports of the Massachusetts Railway Commission. The reports of other railway commissions are either less detailed or relate to street railways that are comparatively new.

Following is a brief summary showing the growth of street railways in Massachusetts.

Year.	Miles of single track.	Miles operated by electricity.	Car miles, millions.	Cars.	Passengers, millions.
1887	470	.....	20.6	2,633	125
1888	588	.....	28.2	2,588	134
1889	574	51	24.3	2,942	148
1890	612	160	26.5	3,247	165
1891	672	289	27.7	3,494	176
1892	755	496	29.7	3,679	194
1893	874	711	34.5	4,040	214
1894	929	825	36.7	4,059	220
1895	1,088	1,016	43.7	4,426	260
1896	1,277	1,241	53.6	4,913	292
1902	2,444	.....	100.3	7,144	465
1903	2,675	.....	117.0	7,618	602

It will be noted that not till 1889 did electricity come into use, and not till 1893 had it practically displaced horse power.

Note that the mileage per car has hardly increased, nor the passengers per car mile.

According to the report for 1908, the assets of Massachusetts street railways were:

Construction	$ 82,934,355
Equipment (rolling stock)	29,699,294
Land and buildings	39,663,442
Other permanent property	1,807,999
Cash	8,170,683
Miscellaneous assets	7,705,688
Total assets	$170,154,909

The mileage was:

	Miles.
Railway line owned (1st track)	2,233.85
Railway line owned (2d track)	441.04
Total main track owned	2,674.89
Sidings, switches, etc., owned	166.70
Total track owned	2,841.59
Main track leased	577.10
Total main track operated	2,741.00

The equipment was as follows:

Box passenger cars	3,876
Open passenger cars	3,742
Total passenger cars	7,618
Other service cars	461
Snow plows	779
Other vehicles (wagons, etc.)	1,650
Electric motors on cars	16,649

We see from the above that the reported cost per mile of main single track operated was:

Construction	$31,005
Equipment	11,103
Buildings and land	15,569
Total	$57,677

It is evident that no reliance can be placed in the so-called cost of construction, for it really represents purchase price and not actual cost of construction.

The cost of equipment, however, appears to be reliable, for it indicates a cost of about $4,000 per car.

There were 17,267 employes; 602,400,874 passengers were carried, and the gross earnings from operation were $30,780,762. The number of car miles was 116,982,089, or 42,700 car miles per mile of track.

Table XXVI gives the operating expense, which I have calculated both in terms of the car mile and of the mile or single track operated.

The repairs of cars and electric car equipment (Items 9 and 10) amounted to $2,429,253. Since the first cost of the equipment was $29,699,294, it appears that repairs amounted to a little more than

8% of the first cost. However, sight should not be lost of the fact that half the equipment consisted of open cars, which are used only in the summer and at a time when the closed (box) cars are mostly idle. Therefore, the cost of repairs would be nearly double the 8% if all equipment were kept constantly busy, making the annual cost of repairs about 16% of the first cost of the active equipment.

These repairs doubtless include renewals.

Unfortunately the cost of rail renewals is not given as a separate item. The number of car miles per mile of track was less than half as many as on the average steam railway of America.

Item 14, Wages of Employes, evidently refers to conductors and motormen, but does not include employes in the power plant.

TABLE XXVI.—OPERATING EXPENSE, MASSACHUSETTS STREET RYS., 1908.

	Total.	Per mi. single track.	Per car mile. cents.
General Expense:			
1. Salaries of officers	$ 690,082	$ 252	0.59
2. Office expenses and supplies	151,174	55	0.13
3. Legal expenses	421,611	154	0.36
4. Insurance	248,972	91	0.21
5. Other general expenses	407,304	148	0.35
Total general expense	$ 1,919,143	$ 700	1.64
Maintenance of Way:			
6. Repairs of roadbed and track	$ 1,273,992	$ 465	1.09
7. Repairs of electric line construction	393,047	143	0.33
8. Repairs of buildings	184,747	68	0.16
Total maintenance of way	$ 1,851,786	$ 676	1.58
Maintenance of Equipment:			
9. Repairs of cars	$ 1,157,680	$ 423	0.99
10. Repairs of electric car equipment	1,271,573	464	1.09
11. Repairs of miscellaneous equipment	75,124	27	0.06
12. Provender and stabling	56,021	20	0.05
Total maintenance of equipment	$ 2,560,398	$ 934	2.19
Transportation Expense:			
13. Electric motive power	$ 3,928,820	$1,434	3.36
14. Wages of employes	7,948,277	2,901	6.80
15. Removing snow and ice	136,002	50	0.12
16. Damages for injuries	1,218,242	445	1.04
17. Tolls for trackage rights	97,033	35	0.08
18. Rents of buildings, etc.	171,182	62	0.15
19. Other transportation expense	710,695	260	0.60
Total transportation expense	$14,210,251	$5,187	12.15
Grand total operating expense	20,541,578	7,497	17.56

Power to Operate Street Cars.—The following data relate to small motor cars.

The record of power consumed on an electric street railway, for the year 1895, is as follows:

Tons (2,240 lbs.) coal	19,172
Car-miles, motor car	5,677,581
Car-miles, trailer car	654,557
Car-miles, total	6,421,638
Car-miles, motor car per day	120
Coal per motor car-mile, lbs.	7.6
Coal per car-mile, lbs.	6.9
Passengers per car-mile	4.1
Ton-miles (2,000 lbs.), passengers at 140 lbs.	1,810,033
Ton-miles (2,000 lbs.), motor car at 6½ tons	36,900,873
Ton-miles (2,000 lbs.), trailer at 2½ tons	1,645,140
Ton-miles (2,000 lbs.), total	40,356,046
Coal per ton mile, lbs.	1.08
Engine hours	25,183
Elec. horsepower hours, total	15,305,254
Watt hours, per motor car-mile	2,032
Watt hours, per ton-mile	286
Watt hours, per pound of coal	266
Coal per electric horsepower, lbs.	2.81
Watts per motor car-mile	16,562
Effort per ton-mile, foot-pounds	103,420
Average pull per ton	19.5
Schedule speed, miles per hour	7.37

The "average pull per ton" is calculated from the consumption of electricity, and not by dynamometer test.

Cost of Operating an Elevated Electric Railway.—"Electric Railway Economics" (1903), by W. C. Gottschall, contains the following actual cost of operating an elevated railway in a large city, operating electric cars at a scheduled speed of 16 miles per hour. The age of the cars is not given, hence no sound conclusions can be drawn from these data as to equipment maintenance:

	Per car mile.
1. Train crews, telegraphers, couplers and yard men	$0.0237
2. Station men, agents, porters and laborers	0.0072
3. Maintenance and upkeep of cars, trucks and motive power	0.0125
4. Repairs of elevated structure and roadway	0.0065
5. Electric power	0.0123
6. Miscellaneous expenses, supplies, etc.	0.0021
7. General expenses, salaries, etc.	0.0084
Total	$0.0727
8. Legal expenses and injuries	0.0053
9. Taxes	0.0065
Grand total	$0.0845

The power was 2 kw. hrs. per car-mile at the central station.

Power to Operate New York Elevated and Surface Cars.—In Manhattan elevated railways it is estimated that the electric power consumed per loaded car is as follows:

	Kw. per car.
Operating (current measured at the car)	21.0
Heating (current measured at the car)	4.8
Lighting (current measured at the car)	1.5
Air pumps (current measured at the car)	0.6
Total (current measured at the car)	27.9
Line loss	7.8
Grand total at the switchboard	35.7

On the surface lines in Manhattan about 16 kw. per car in summer, and 25 kw. in winter, is required.

The power required at the switchboard to drive 224 elevated motor cars and 1,247 surface cars in Brooklyn was determined to be as follows:

	—Kw. per car.—	
	Surface car.	Elevated car.
Operation	15.95	36.85
Heating	3.30	8.25
Lighting	1.10	1.10
Total	20.35	46.20

Weight and Power of Motor Cars.—In the early days of electric railways small motor cars with bodies only 16 or 18 ft. long and with two 15-hp. motors were common. Such cars are still common in the smaller towns and cities, and are not entirely out of use even in the larger cities.

A large city car, 30 tons, with double trucks, equipped with four 40-hp. motors (160-hp. total), and seating 44 people, is now the standard for heavy city traffic.

Interurban cars vary considerably, but the following is fairly typical: Car 50 ft. long, seating 42 people, double trucks, weighs 34 tons, is equipped with four 75-hp. motors (300-hp. total), and maintains a schedule speed of 30 miles per hour.

Cost of Maintenance of Motor Cars.—Although considerable has been published on this subject, very little of value has thus far appeared. The reasons why the data are unsatisfactory are these: (1) The age of the cars is not given. Obviously new cars entail much less expense for repairs than old cars. (2) The first cost of the cars, the size of the motors and the size of the cars are not stated.

Pending further information, I recommend estimating the annual cost of repairs of motor cars (incl. motors) at 12% of the first cost.

If a large motor car costs $7,500, the average annual maintenance over a long period of years (20) would then be $900. If the car travels 30,000 miles per year, its maintenance will then be 3 cts. per car-mile.

If the life of a car is 25 years, and no sinking fund is established, renewals being paid for annually as they become necessary, then

4% of the first cost will be the average annual expenditure for renewals when distributed over a long term of years. Renewals (4%) being ⅓ as much as current repairs (12%), we have 1 ct. per car-mile for renewals of a $7,500 motor car, making a total of 4 cts. per car mile for repairs and renewals of a $7,500 car, when distributed over a long term of years.

In 1902 the repairs and renewals of street cars in Massachusetts were 1.65 cts. per car-mile, and the first cost of the average car was $3,000. If the cost had been $7,500, as above assumed for large cars, we should have $2\frac{1}{2} \times 1.65 = 4.12$ cts. per car-mile for repairs and renewals. This makes an excellent check upon my estimate of 16% of the first cost for repairs and renewals of equipment. It was about 1888 that electric lines began to be built in Massachusetts, so that repairs and renewals of equipment 24 years later (1902) are a fair index of what may be expected in the future. Repairs and renewals of equipment per car-mile may rise still higher in Massachusetts, even with cars of the present cost, for the mileage of street railways doubled about every six years between 1890 and 1902.

The cost of maintenance of the power plant should be estimated in a manner analogous to the foregoing.

Railway Operating Expenses, Etc.—The annual reports of the Interstate Commerce Commission and the reports of the various state railway commissions contain valuable data on operating expenses.

The *miles of trackway* include all 1st, 2d, 3d and 4th tracks, and amounted to 243,322.

The *miles of roadbed* (or "line") include only 1st track, and amounted to 222,340.

The *miles of track* include all tracks, main, branch, side and yard, and amounted to 317,083.

There are nearly 1.43 miles of track per mile of roadbed in America.

According to the report of the Interstate Commerce Commission for the year 1906, the following was operating expense, given for each item as a percentage of the total:

Maintenance of Way and Structures:	Per cent.
1. Repairs of roadway	10.726
2. Renewal of rails	1.432
3. Renewal of ties	2.509
4. Repairs and renewals of bridges and culverts	2.207
5. Repairs and renewals of fences and road crossings, signs and cattle guards	0.413
6. Repairs and renewals of bldgs. and fixtures	2.304
7. Repairs and renewals of docks and wharves	0.241
8. Repairs and renewals of telegraph	0.177
9. Stationery and printing	0.030
10. Other expenses	0.257
Total	20.296

	Maintenance of Equipment:	
11.	Superintendence	0.561
12.	Repairs and renewals of locomotives	8.080
13.	Repairs and renewals of passenger cars	1.968
14.	Repairs and renewals of freight cars	9.009
15.	Repairs and renewals of work cars	0.268
16.	Repairs and renewals of marine equipment	0.232
17.	Repairs and renewals of shop machinery and tools	0.668
18.	Stationery and printing	0.047
19.	Other expenses	0.563
	Total	21.396
	Conducting Transportation:	
20.	Superintendence	1.776
21.	Engine and roundhouse men	9.275
22.	Fuel for locomotives	11.119
23.	Water supply for locomotives	0.650
24.	Oil, tallow and waste for locomotives	0.385
25.	Other supplies for locomotives	0.250
26.	Train service	6.375
27.	Train supplies and expenses	1.557
28.	Switch, flag and watchmen	4.357
29.	Telegraph expenses	1.751
30.	Station service	6.307
31.	Station supplies	0.611
32.	Switching charges—balance	0.293
33.	Car per diem and mileage—balance	1.231
34.	Hire of equipment	0.201
35.	Loss and damage	1.375
36.	Injuries to persons	1.139
37.	Clearing wrecks	0.200
38.	Operating marine equipment	0.685
39.	Advertising	0.422
40.	Outside agencies	1.352
41.	Commissions	0.017
42.	Stock yards and elevators	0.055
43.	Rents for tracks and yards	1.751
44.	Rents of other buildings and other property	0.324
45.	Stationery and printing	0.629
46.	Other expenses	0.245
	Total	54.432
	General Expenses:	
47.	Salaries of general offices	0.826
48.	Salaries of clerks and attendants	1.372
49.	General office expenses and supplies	0.263
50.	Insurance	0.481
51.	Law expenses	0.452
52.	Stationery and printing (g. o.)	0.182
53.	Other expenses	0.300
	Total	3.876
	Grand total (per cent)	100.000
	Grand total	$1,533,404,385

The cost of operating expense, expressed in various units, was as follows:

Per train mile	$1.3706
Per car mile (approximately)	0.0833
Per mile of roadbed (line)	6,896
Per mile of trackway	6,303
Per mile of track	4,836

By multiplying the percentage given for any item in the table of operating expense by any of the above unit costs of operation, the corresponding item unit cost is obtained.

Thus, Item 22, Fuel, is 11.119%. The total operating expense per train mile is $1.37. Hence $1.37 × 11.119% = $0.1523 per train mile for fuel.

Thus, Item 2, Removals of Rails, is 1.432%. The total operating expense per mile of trackway is $6,303. Hence $6,303 × 1.432% = $90.21 per mile of trackway for rail renewals.

In 1906, the total equipment of American railways was:

Locomotives:	
Passenger	12,249
Freight	29,848
Switching	8,485
Unclassified	1,090
Total locomotives in service	51,672
Cars:	
Passenger	42,262
Freight	1,837,914
Company service	78,736
Total cars in service	1,958,912

It will be noted that there were 3.45 passenger cars per passenger locomotive, and 61.6 freight cars per freight locomotive.

The above does not include freight cars owned by private companies, on which the railways pay a mileage, the value of which is estimated to be $72,000,000. Nor does it include cars owned by the Pullman Co., estimated at $51,000,000. If the average freight car owned by private individuals is worth $1,000, there would be about 72,000 of them. If the average Pullman is valued at $10,000, there would be 5,000 of them. These numbers would increase the number of freight cars above given by about 4%, and would increase the number of passenger cars by about 12%.

The average weight of the locomotives (exclusive of tender) was 66 tons, of which 54 tons was on the drivers. The average tractive power was 24,300 lbs.

The classification of freight cars was as follows:

Box cars	843,118
Flat cars	146,908
Stock cars	64,202
Coal cars	686,717
Tank cars	5,324
Refrigerator cars	31,782
Other cars	55,584
Total	1,833,635

The average capacity of these cars was 32 tons.

The following were the employes:

		Per day.	Total per year.
6,090	general officers	$11.81	$ 15,911,369
6,705	other officers	5.82	12,870,203
57,210	general office clerks	2.24	41,227,916
34,940	station agents	1.94	22,571,595
138,778	other station men	1.69	70,702,517
59,855	engine men	4.12	74,581,454
62,678	firemen	2.42	44,247,306
43,936	conductors	3.51	47,417,403
119,087	other trainmen	2.35	81,884,828
51,253	machinists	2.69	40,326,031
63,830	carpenters	2.28	40,961,083
199,940	other shopmen	1.92	111,524,564
40,463	section foremen	1.80	23,519,671
343,791	other trackmen	1.36	112,196,214
49,659	switch tenders, crossing tenders and watchmen	1.80	27,939,001
36,090	telegraph operators and dispatchers	2.13	24,729,669
8,314	employes—acctg. floating equipment	2.10	4,776,654
198,736	all other employes	1.83	103,414,175
1,521,355	Total		$900,801,653

By multiplying the average daily wage by the total number of men in each class and dividing this product in the total annual payment, the average number of days worked can be ascertained. For all except "general officers" (240 days), and for "other trackmen" (270 days), the average is close to 315 days. The average employe received nearly $600 per year.

In the case of trainmen, it must be remembered that the wage shown is not the true average daily income, for they are usually paid on an arbitrary basis, say 100 miles of run constituting a day's work.

The following is a summary of the service performed by the railways according to the 1906 report.

1.	Passengers carried	797,946,116
2.	Passenger miles	25,167,240,831
3.	Passenger train miles	479,037,553
4.	Passengers per train, average	49
5.	Passenger's journey, miles	31.54
6.	Freight, tons, excluding those received from connecting roads	896,159,485
7.	Freight, ton miles	215,877,551,241
8.	Freight, ton miles per mile of roadbed	982,401
9.	Freight, train miles	594,005,825
10.	Freight, car miles	16,589,958,024
11.	Freight, tons per train	344.4
12.	Freight, average haul, regarding all railways as one system, miles	240.9
13.	Total revenue passenger and freight train miles	1,105,877,091

Item 13 would be the sum of items 3 and 9, were it not that there were also mixed trains (passenger and freight combined).

It will be noted that the number of passenger car miles is not given, but it can be closely approximated, as follows:

Dividing the 42,262 passenger cars by the 12,249 passenger locomotives, we find there were 3.45 passenger cars per passenger locomotives.

Hence multiplying the 479,037,553 passenger train miles by 3.45, we have 1,612,678,558 passenger car miles. This assumption implies that there would be as many passenger cars as locomotives in the shops, or otherwise idle. The Pullman sleeping cars are not included in the above, and as we have seen, they would add about 12% to the total number of passenger cars. On this assumption, the total number of passenger car miles would be about 1,806,200,000.

If we regard a locomotive and its tender as equivalent to two cars, multiplying the total train miles by 2 gives us the locomotive and tender car miles.

Hence we have:

Freight car miles	16,589,958,024
Passenger car miles	1,806,200,000
Total car miles	18,396,158,024
Locomotive and tender miles	2,211,754,182
Total car and engine miles	20,607,912,206

Since there were 243,322 miles of trackway, we have 20,607,912,209 ÷ 243,322 = 84,700 cars per year passing over each mile of trackway.

The importance of this deduction will be seen when we come to consider the wear of rails.

If we divide Item 13 (the total train miles), by the 243,322 miles of trackway, we have 4,540, which is the number of trains per year per mile of trackway. If we divide this 4,540 by 365 (the number of days in a year), we have a little more than 12, which is the number of trains per day both ways, or 6 trains per day each way on each trackway.

If we divide 16,589,958,024 (the number of freight car miles) by 594,005,825 (the number of freight train miles), we get nearly 28, which is the average number of freight cars per freight train.

We have seen that there were about 3.5 passenger cars per passenger train, plus nearly 0.5 Pullman car, or a total of 4 cars per passenger train.

Since about 45% of the trains were passenger trains and 55% freight, the average of both passenger and freight trains was about 17 cars.

Dividing 594,005,825 (the freight train miles) by 29,849 (the number of freight locomotives), we get nearly 20,000 miles per freight locomotive per year. This is not quite 55 miles per day.

Dividing 479,037,553 (the passenger train miles) by 12,249 (the number of passenger locomotives), we get nearly 40,000 miles per year, or not quite 110 miles per day. The average of both freight and pasenger locomotives was about 25,500 miles per locomotive per year.

We have seen that there were 62 freight cars per freight locomotive, and that there were 28 cars per freight train. Hence

there were about 62 — 28 = 34 freight cars not moving in trains, or about 34 ÷ 62 = 55% of the car time was spent on sidings and in yards not attached to a locomotive.

If 45% of the time was spent moving with a freight locomotive, and if (as we have seen) a freight locomotive averages 55 miles per day, then 55 × 45% 24.75 miles were averaged per freight car per day. This may be arrived at with greater accuracy thus: 16,589,958,000 (freight car miles) divided by 1,958,912 (freight cars), gives nearly 8,460, which is the car miles per car per year, which is equivalent to 23.2 car miles per day. This checks very well with the approximate method first given. That method involved the assumption that time lost during shop repairs is the same for freight cars as for locomotives, which is not quite true, since about 5% of the total freight cars and 8% of the total locomotives are constantly in the shops. It also involved the assumption that there are not more locomotive crews than locomotives, which is not far from correct, since there were 59,855 enginemen to operate the 51,672 locomotives.

The average haul of a ton of freight was 241 miles, which would take nearly 10½ days at 23.2 miles per day, including time spent in yards and sidings, loading and unloading; but, since 45% of the time (as we have seen) was spent on the road, 4½ days of car time were spent on the road traveling and 6 days on the side tracks, etc.

The empty freight car mileage was 31.2% of the total freight car mileage.

Since the average number of tons per freight train was 344, and since there were 28 cars per freight train, the average carried by all cars (loaded and empty) was 344 ÷ 28 = 12.3 tons nearly. Since 68.8% were loaded cars, the average loaded car carried 12.3 ÷ 68.8 = 17.9 tons.

The income was:

Passenger revenue	$ 510,032,583
Mail	47,371,453
Express	51,010,930
Other earnings, passenger service	11,314,237
Freight revenue	1,640,386,655
Other earnings, freight service	5,645,222
Other earnings from operation	59,741,198
Unclassified	262,889
Total earnings from operation	$2,325,765,167
Income from other sources	256,639,591
Total earnings and income	$2,582,404,758

Considering all the railways as one system, we have the following income account:

Earnings from operation	$2,325,765,167
Clear income from investments	60,520,306
Gross earnings and income	$2,386,285,473
Operating expense (incl. leased lines)	1,537,448,702
Net earnings and income	$ 848,836,771
Net interest on funded debt	$ 305,337,754
Interest on current liabilities	11,653,076
Taxes	74,785,615
Total fixed charges and taxes	$ 391,776,445
Balance available for dividends	$ 457,060,326
Net dividends	$ 213,555,081
Balance available adjustments and improvements	$ 243,505,245

The revenue per train mile was:

All trains	$2.075
Passenger trains	1.203
Freight trains	2.608

The average freight revenue was 0.748 ct. per ton mile. The average passenger revenue was 2.003 cts. per passenger mile. The operating revenue per mile of roadbed was $10,460. The operating expenses were 66.08% of the operating income.

Average Life of Rails and Cost of Rail Renewals.—In determining the annual depreciation of rails subject to a given traffic I made the following analysis for the Railroad Commission of Washington.

The average cost rail renewals in the United States was $75 per miles of trackway, or $82 per mile of roadbed, or $58 per mile of track, as deduced from the 1904 report of the Interstate Commerce Commission. The mile of trackway is the preferable unit, for it represents the mile of 1st, 2d, 3d and 4th track. Naturally, the wear on rails in side tracks is almost insignificant.

If the annual rail wear is $75 per mile of trackway, it remains only to know the average cost of a mile of rails to arrive at the percentage of annual renewals. The weight of rails in the average track is about as many pounds per yard of rail as the weight in tons of the average locomotive.

In 1904 the average locomotive weight was 60 tons, and it is reasonable to suppose that the average weight of rail was not much in excess of 100 tons of rails per mile of track.

Now, if we can ascertain the average cost of a ton of rails delivered to the distributing point of the average railway, we shall be able to estimate the value of a mile of rails in the average track. To determine the "center of gravity" of the railway mileage of America, I assumed that the center of each state would represent, with sufficient accuracy, the "center of gravity" of the railway mileage of that state. To ascertain the "center of gravity" of the total mileage, co-ordinate axes were drawn and the distances from these axes to the center of each state were measured.

The abscissas and ordinates thus obtained were multiplied by their respective mileages of railway line. The sums of these prod-

ucts were divided by the total mileage of all lines, and the quotients were, of course, the abscissa and ordinate of the "center of gravity" of the entire railway mileage. This was found to be at a point not far north of St. Louis, Mo.

The practice of railways has been to charge ½ ct. per ton mile for freight on rails, so that, in the year 1904, freight to the "center of gravity" of railway mileage could not have cost much to exceed $3 per ton from Pittsburg, or $1.50 from Chicago. The standard price of rails was $28, so the total cost delivered was not to exceed $31 per ton, and doubtless averaged less than $30. As a matter of fact, rails cost the Northern Pacific and the Great Northern less than $29.50 per ton delivered at St. Paul, at that time, so that we are safe in saying that the average cost of rails delivered to the average railway distributing point was not far from $30 per ton. Hence enough new rails for an average mile of track (100 tons) cost about $3,000. Since rail renewals actually cost $75 per mile of trackway, we see that rail renewals cost 2½% of the value of the rails in a mile of trackway. This is on the assumption that renewals of rails in side tracks was a comparatively insignificant item, which is practically so.

It must not be hastily assumed, however, that the life of the average rail is 40 years, for the fact is that it is less than half that. The $75 per mile of trackway represents cost of new rails *minus the scrap value, or relaying value, of the old rails.* There is, at present, no means of knowing exactly what the practice of all railway companies is as to the credit given on their books for the rails that are replaced, but it is certain that an old rail is worth at least its scrap value at the mills less the freight to the mills, or about $12 per ton. As a matter of fact, relaying rails are worth considerably more, and since many old main line rails are used for branch lines and particularly for side tracks, it is evident that the credit given to old rails will somewhat exceed $12. From study of the accounting practice of several large railways, I concluded that $15 per ton would be not far from the average credit. Hence the net cost of the new rails (after deducting the credit for the old rails replaced) would be $15 per ton; and, since the annual rail renewals averaged $75 per mile of trackway, there would be 5 tons of new rails laid per mile per annum. Hence in a track averaging 100 tons of rails per mile, this would mean 5% renewals every year, or a rail life of 20 years in the main and branch line tracks.

It is obvious that rail wear depends upon the density of traffic. In 1904, there were 829,500 tons of freight carried over each mile of roadbed, or 746,500 tons per mile of trackway. There were 4,370 trains that passed over each mile of trackway, or nearly 12 trains per day, of which 53% were freight, 44% passenger and 3% mixed trains. If we count an engine and its tender as equivalent to two cars, there were 78,540 cars passed over each mile of trackway during the year.

Wellington, in his "Economic Theory of Railway Location," has erred badly in his estimate of rail wear. He states that a rail

should carry 300,000 to 500,000 trains (of 500 tons each) before replacement. With 4,370 trains per year (the average of the U. S. in 1904), Wellington's rule would indicate a rail life of 100 years! This is at least five times the actual life of 20 years above shown. As I have shown on page 1462, about 22% of the average railway line is curved. Even assuming that the average curve is as sharp as 6°, which is, of course, far sharper than the average, and that a 6% curve increases the wear 100%, we see that the increased wear due to curves would be only 22% of 100% = 22% greater than if the entire mileage of track were tangent.

Part of Wellington's error arises from the assumption that a rail head can lose half its weight before renewal of the rail is necessary. As a matter of fact, Northern Pacific tests have shown that not more than one-quarter of the weight of the head is lost before renewals are made. On an 80-lb. rail, this would mean that when about 10% of its entire weight is lost by abrasion, the rail is unfit for further economic service, except in sidings and the like. Wellington was also misled by a belief that prevailed in the early 80's that a steel rail would last many times as long as an iron rail, a belief which was much too optimistic, as subsequent events have proved.

In selecting a proper unit in which to measure rail wear there has been much dispute. Wear may be measured in three ways: (1) In terms of the number of tons of gross weight that pass over the rail before it is worn out; (2) in terms of the number of trains; or (3) in terms of the number of cars. Wellington favored the train as the unit, for he says: "The locomotive alone causes by far the greater portion of this wear." He cites the opinion of Launhardt, a German writer, to the effect that the engine causes fully half the wear—a conclusion apparently based upon nothing but theory. He also cites some theoretical deductions of Mr. O. Chanute. In brief, there was even then no real evidence to prove the contention that a locomotive causes as much wear as the rest of the train. At present, when wheel loads on the largest freight cars equal those on the average locomotive, the argument that a locomotive causes half the wear on a rail is manifestly absurd.

I am satisfied that rail wear is not a function of the number of gross tons carried, nor of the number of trains, but of the number of cars that pass over the rail. Nor do I think that the weight on the wheels is a very material factor in the couse of wear. Rail wear on tangents is due mainly to the grinding of particles of grit and steel between the wheel and the rail. The abrasion due to any grinding action is by no means proportionate to the pressure.

In sawing wood the weight of a cross-cut saw is sufficient to produce rapid abrasion of the wood, and nothing whatever is gained by bearing down on the saw. So, too, in cutting stone with grit or chilled shot, a comparatively light pressure is quite as effective in abrading the stone as is a heavy pressure: It should be remembered that it does not take a great weight applied to a grain of sand to produce a very large *unit pressure* between the grain of sand and the weight. It is this unit pressure that counts,

and it needs be only sufficient to cause slight penetration cf the sand into the steel to result in abrasion. What is true of sand grains is true of all other particles between, or minute protuberances and irregularities upon the two abrading surfaces—the rail and the wheel.

As we have seen, the average rail in an American trackway has a life of about 20 years, when it carries 78,500 cars per year. Hence it carries 20 × 78,500 = 1,570,000 cars during its active life.

I think it is more than mere coincidence that the life of a steel rail in a street "tramway" in England has averaged 1,500,000 cars, as shown below. At any rate, it is evident that rail wear is far more nearly a function of the number of cars that pass over the rail than of any other unit yet suggested. It will probably be found, however, that the most exact unit in which to measure wear is the number of *wheels* that pass over a rail.

Curvature of Railways.—Since curvature affects the wear of rails, and thus affects the cost of track maintenance, it is of interest to know what per cent of the average railway track is curved. The following statistics, gathered in 1901, throw light on this matter.

Road.	Miles of roadbed.	Per cent curved.
Bur. Ced. R. & N.	1,234	21
Chicago & Alton	900	12
C. & E. I.	725	12
C. & N. W.	5,562	19
C. M. & St. P.	6,423	20
C. G. W.	946	20
C. O. & G.	659	17
C. R. I. & P.	3,630	21
Del. & H.	723	35
Del. & Lack.	908	35
Denver & R. G.	1,675	30
Ill. Centr.	3,996	16
Lehigh Valley	461	36
Long Island	379	16
Mich. Centr.	1,642	14
M., St. P. & Ste. Marie	1,039	14
Mo. K. & T.	1,988	20
Mo. Pacific	5,329	21
Nash. C. & St. L.	1,195	25
N. Y. C. & H. R.	2,828	38
N. Y. C. & St. L.	512	6
Pere Marquette	1,743	15
Penn. (West of Pittsburg)	2,762	21
Penn. (East of Pittsburg)	4,287	34
St. L. & S. F.	1,640	29
Seaboard Air Line	1,049	25
So. Pacific (Pacific System)	5,155	24
Tex. & Pacific	1,582	5
Union Pacific	3,000	20
Wisconsin Central	961	20
Total	64,933	22.15

Life of Rails on an English "Tramway."—Mr. T. Arnall gave the following data in a paper read in 1892 before the Tramway's Institute of Great Britain and Ireland.

At Birmingham, a steam motor car weighing 10 tons hauls a large car holding 60 passengers over girder rails weighing 98 lbs. per yd. After 8 years experience with a very heavy traffic, Mr. Arnall concluded that such a rail will carry less than 750,000 steam cars before needing replacement. The life of the driving wheel tires is only 25,000 miles, due to steep grades (5%), and frequent use of sand. If we include the passenger car, we see that a rail carried 1,500,000 cars before it was worn out.

Average Cost of Maintenance of Equipment in America.—Individual railways are apt to show quite wide fluctuations from year to year in the cost of repairs and renewals of rolling stock. This is due largely to the financial condition of the company, and often to the desire to make an unusually good showing as to net earnings. On the other hand, the average of all roads in America would be the best possible criterion of maintenance costs were the actual first cost of the equipment known. Unfortunately it is not known, but we can estimate the approximate first cost with considerable accuracy, using the annual reports of the Interstate Commerce Commission and applying unit prices to various classes of equipment there described.

The report for 1906 shows that there were 51,672 locomotives of all kinds in the United States, and that the "repairs and renewals of locomotives" cost $123,893,482, which is nearly $2,400 per locomotive for the year. The average weight of each locomotive was 66 tons, not including the tender, with a weight of 54 tons on the drivers.

A 66-ton locomotive costs about $12,000 new, hence the repairs and renewals for 1906 averaged 20% of the first cost.

While the rules of the Interstate Commerce Commission require the railways to charge to "renewals" the full cost of a new locomotive bought to replace an old one, the railways ignore this order, and properly charge to capital account the *excess* value of the new locomotive over the value of the old one. Hence the railway maintenance accounts show true repairs and renewals cost. It should be noted, however, that the amount charged to repairs and renewals of locomotives should be increased by nearly 10% of the 20%, distributed as follows:

	Per cent.
Superintendence of maintenance	2.9
Repairs and renewals of shop machinery	3.4
Stationery and printing	0.2
Other expenses	2.9
Total	9.4

This does not include repairs and renewals of shop buildings nor interest on the shop plant, nor "general expenses" of the entire railway systems, the latter being nearly 3.9% of the total operating expense.

However, if we add only 10% to the cost of "repairs and renewals" of each locomotive to cover the above named items of direct costs of shop machinery, repairs, etc., we have a total of $2,640 per locomotive, or 22% of the first cost.

The 1904 report shows that locomotives averaged 60 tons weight and that "repairs and renewals of locomotives" averaged $2,250 per locomotive. Since the average weight was nearly 10% less than for 1906, the "repairs and renewals" should be about 10% less, and such, in fact, is the case.

In 1906, the average locomotive traveled 27,400 revenue train miles. The actual locomotive mileage was somewhat in excess of this, but no data are given from which it can be computed.

Since the "repairs and renewals," which we shall now call 22% of the first cost of locomotives, includes true depreciation (renewals of entire locomotive), we must deduct depreciation to arrive at true repairs. There is no available record of exactly what this has averaged in America, but my study of the equipment records of the Great Northern, Northern Pacific and other lines, has led me to conclude that about 3.6% is the least percentage of locomotives that have been retired from service annually. This is equivalent to a life of 27.8 years. Due to the rapid increase in train loads in past years it is probable that from 4 to 5% of the locomotives have been retired annually. If we assume that 4% were retired in 1906, we have 22%—4% = 18% of the first cost spent for true repairs.

Of the 51,672 locomotives, 58% were freight, 16% switching, 24% passenger, and 2% unclassified.

In 1906 there were 1,833,635 freight cars whose rated capacity was 32 tons. The "repairs and renewals of freight cars" amounted to $138,141,295, or nearly $76 per car for the year. The first cost of a 32-ton car probably was about $600, so that "repairs and renewals of freight cars" were about 12.7% of the first cost, to which should be added fully 10% (for reasons given) of this 12.7%, making a total of 14% as the annual cost of repairs and renewals. If 4% of the freight cars were "retired" in 1906, this would leave 10% as the cost of true repairs.

In 1906 there were 42,262 passenger cars, and their "repairs and renewals" totaled $30,177,532, or $715 per car. The probable average first cost of passenger cars is about $6,000. Hence about 12% was spent for "repairs and renewals" to which should be added (for reasons above given) fully 10% of the 12%, making a total of about 13.2%.

If 4% were retired in 1906, the cost of true repairs was 9.2%. However, the percentage of passenger cars retired is somewhat less than freight cars. Hence true repairs of passenger cars doubtless were nearly 10% of the first cost.

Summing up we see that true repairs of equipment were about the following percentages of their first cost:

	Per cent.
Locomotives	18
Freight cars	10
Passenger cars	10

Repairs and renewals (= repairs and depreciation), were:

	Per cent.
Locomotives	22
Freight cars	14
Passenger cars	13.2

Cost of Maintenance of Equipment, N. P. Ry.—In making my appraisal of the equipment on the Northern Pacific Ry., as of June 30, 1906, I found the company's books showed the following original cost:

1,005 locomotives	$12,977,823
478 passenger and accommodation cars	2,805,197
127 sleeping and dining cars	1,588,792
195 baggage, express and postal cars	685,750
37,584 freight cars	22,843,823
Floating equipment	497,102
Total	$41,353,487

This gives an average unit cost of:

Locomotive	$12,970
Passenger car	5,890
Sleeping car, etc	12,480
Baggage car	3,530
Freight car	610

The average first cost of each of three classes of equipment, and the average amount spent in repairs and renewals for the fiscal year 1906, were as follows:

	First cost.	Annual maintenance.	Per cent of first cost.
1,005 locomotives	$12,970	$2,540	19.5
800 passenger cars	6,340	630	10.0
37,584 freight cars	610	69	11.3

This annual maintenance (for the year 1906) includes repairs and renewals, but the "superintendence" and "other expenses" are not included, and they amounted to about 3.6% additional.

The locomotives average 78 tons weight, not including the weight of the tender; their average actual ages was 10.7 years, but their average "weighted age" was 8.6 years.

The average "weighted age" of the passenger cars was 11.1 years, and of the freight cars, 8.2 years.

At the prices now prevailing, this equipment would cost 10 to 15% more if bought new.

There were 137 switching engines in the above number and there were 229 passenger engines and 639 freight engines, and the 868 engines averaged 28,600 miles each, including all train and engine mileage, which was as follows:

Passenger train miles	8,057,721
Locomotives helping passenger trains	393,974
Mixed train miles	849,035
Freight train miles	12,248,582
Locomotives helping freight trains	2,097,913
Non-revenue train miles	1,229,736
Total	24,876,961

Since the revenue train mileage was 21,155,338, the 868 locomotives each averaged 24,300 revenue train miles.

The car mileage was:

Passenger cars	59,298,843
Freight cars	415,358,345

The average was 6.66 passenger cars per passenger train, and 31.71 freight cars per freight train, of which 23.15 were loaded with 17.30 tons each = 400.47 tons load per train.

The total spent for maintenance of all equipment (excepting marine) was $6,000,000, including superintendence and repairs of shop machinery. Since the first cost of all this equipment was $41,000,000, we see that the average cost of repairs and renewals was nearly 15% for the year 1906.

Taking all locomotives and cars of all kinds (freight and passenger), the average first cost of each unit was $1,000 and the average cost of repairs and renewals was $150 or 15%. The value of this deduction will be apparent when we come to consider the percentage that should be allowed for annual repairs and renewals of electric motor cars. Many absurdly low estimates have been made as to the latter, based upon short experience with comparatively new equipment, and also without any regard as to the actual first cost of the equipment.

Life of Railway Cars and Locomotives, and Cost of Repairs, S. P. Ry.*—Mr. William Mahl, comptroller of the Union Pacific and Southern Pacific railways, gives some valuable data as to the life of equipment on the Southern Pacific Railway.

The following are averages for the period of six years, 1902 to 1907, the costs being the average cost per year:

Class.	Number Serviceable.	Expenditure on each per annum. Repairs.	Vacated.
Locomotives	1,540	$3,165	$183
Passenger cars	1,504	759	104
Freight cars	42,983	70	17

In "repairs" are included the annual expenditure for repairs and renewals of each locomotive or car, other than the expenditure for equipment "vacated," or retired. In "vacated" is included the cost of equipment destroyed, condemned and dismantled, sold or changed to another class. In 1903 there was a fire which destroyed $225,000 worth of passenger cars, bringing up the cost per car "vacated" to $234 for that year, as against an average of $82 per car per year for the other five years of the period. Hence the $104 for passenger cars "vacated," as above given, is probably too high for a fair average.

From 1891 to 1907, a period of 17 years, the average number of freight cars "vacated" each year was 3.63% of the total number in service. Dividing 100 by this 3.63, we get 27½, which is, therefore, the average life in years of each freight car. These cars were nearly all wooden cars, of which the cost of a box car did not exceed $450, excluding air brakes.

*_Engineering-Contracting_, Oct. 23, 1907.

In the six-year period (1902 to 1907) the following was the record of equipment vacated:

	Locomotives.	Cars. Passenger.	Freight.	Road service.
Total number	294	299	11,797	468
Av. price per locomotive or car:				
Credited to replacement fund.	$9,298	$4,228	$553	$567
Charged to operating exp.....	5,742	3,140	372	380
Proceeds from sale or salvage.	3,556	1,087	180	188

Since there were 294 locomotives "vacated" in six years, the average was 49 per year out of the 1,540 in service, or 3.2%, which is equivalent to a life of 31 years. The life of passenger cars was practically the same.

There were nearly 2,000 freight cars "vacated" per year out of an average of 42,983 in service, or nearly 4.7%, which is equivalent to a life of but little more than 21 years. But in the years 1906 and 1907 6,338 cars were vacated, which is more than half of all vacated in the six-year period, indicating an unusual amount of replacement. This is also borne out by the fact that for the 17-year period the life of freight cars averaged 27⅓ years, as above stated.

Percentage of Engines Laid Off for Repairs.—In estimating the number of pits required in shops for repairing 1,000 locomotives on the St. Louis and San Francisco Ry., in 1907, various data were used, from which it was concluded that 70 pits would be needed. This is equivalent to 7% of the total number of locomotives constantly in the repair shops. However, many large railways count on 8% of the locomotives constantly in the shops. The records of the St. L. & S. F. showed that there had been 288 days worked each year by the men in the shops. Each engine was estimated to spend 20 days in the shop once a year, and to travel 30,000 miles between these periods of general repairs.

It is interesting to note how greatly the percentage of engines laid off for repairs has been reduced within recent years. On the Pennsylvania Ry., from 1851 to 1881, the average was nearly 18% constantly in the shops; for the years 1881 to 1884, the average was nearly 15%.

Percentage of Freight Cars Laid Off for Repairs.—This percentage is ascertainable with great accuracy, for it is shown in the weekly statistical bulletins issued by the American Railway Association of Car Efficiency (Chicago). The average number of freight cars constantly in the shops is about 5 to 5½% of the total cars in service.

Price of Locomotives.—Mr. Wm. P. Evans, of the Baldwin Locomotive Works, gives the following:

Type of Locomotive.	1885. Weight, lbs.	Price.	Price per lb. cts.	1905. Weight, lbs.	Price.	Price per lb. cts.
American	80,857	$6,695	8.28	102,200	$9,410	9.20
Atlantic	....	....	....	187,200	15,750	8.30
Mogul	72,800	6,662	9.12	....	......	....
Pacific	....	....	....	227,000	15,830	7.00
Ten wheeler	85,000	7,583	8.92	156,000	15,690	8.80
Consolidation	92,400	7,888	8.54	192,460	14,500	7.50

The price per pound is figured from the total weight of the engine with three gages of water in the boiler, but excluding the tender.

Cost of Shop Machinery.—Mr. M. K. Barnum gives the following as the actual cost of shop machinery and tools for several different locomotive repair shops:

Shop.	Number of tools.	Locomotives. At one time.	Locomotives. During year.	Area of shops sq. ft.	Cost of tools.
A	96	9	120	47,300	$76,600
B	254	16	216	62,000	188,100
C	226	22	300	131,300	147,400
D	237	22	300	96,000	174,300
E	282	50	600	238,000	264,300

He estimates the average useful life of shop machinery and tools at 20 years.

Cost of Stopping Trains.*—Mr. J. A. Peabody states that an official of a Western railway gave him the following as the cost of stopping trains, determined by experiment.

An 8-car passenger train, weighing 530 tons, including engine and tender half loaded, from and to a speed of 50 miles per hr., costs as follows per stop:

	Lbs.
Coal to stop train (air pump)	30
Coal to accelerate train (estimated)	275
Total coal	305

	Per stop.
305 lbs. coal, at $2.15 per ton	$0.33
Brake shoe wear and tire wear (from laboratory tests)	0.03
Wear of brake and draft riggings, etc. (estimated)	0.06
Total	$0.42

The lost time in starting and stopping on a straight, level track, averaged 145 secs., or nearly 2½ mins. This is the actual loss from the time that would have been required to make the trip had no stop been made.

The corresponding items of cost of starting and stopping a 2,000-ton freight train (80 cars) from and to a speed of 35 miles per hr. were:

	Lbs.
Coal to stop train (air pump)	50
Coal to accelerate train	500
Total coal	550

	Per stop.
550 lbs. coal, at $2.15	$0.56
Brake shoe wear	0.15
Other items, as classified above	0.29
Total	$1.00

**Engineering-Contracting*, Feb., 1906, p. 49.

Cost of Handling Locomotives at Terminals.—Mr. Charles H. Frye gives the following costs of handling locomotives at terminals in 1903.

On the St. Louis & San Francisco line, the average cost per engine per time handled was $1.57 for wages of hostlers and assistants, fire cleaners and asphalt men, front end cleaners, wipers, boiler washers and assistants, sand dryers, laborers or sweepers and callers.

On the Norfolk and Western, the cost was $1.30 for repairs plus $0.52 for watching and hostlering, total $1.82 per engine per time.

On the Mobile and Ohio, 4,832 locomotives were handled at the following labor cost per time:

Hostlers	$0.30
Boiler washers	0.10
Callers (calling engine crew)	0.08
Sand dryers	0.03
Coalers	0.80
Wipers	1.13
Machinists	0.36
Boiler makers	0.12
Truck repairers	0.13
Total	$3.05

On the Texas & Pacific the cost of despatching, in and out of terminals, was 2 cts. per engine mile, or $2.21 per engine per time.

On the Wabash Ry., 17,060 engines were despatched by 636 men, during 1903, at the following labor cost per engine per time:

Repairs	$0.98
Handling	0.84
Total	$1.82

On the Lake Shore & Michigan Southern, the cost of all roundhouse expenses, including skilled mechanics on ordinary running repairs, was:

Skilled mechanics	$1.87
Other labor	1.73
Total	$3.60

On the Seaboard Line, 7,615 engines were despatched at the following unit cost:

Repairs	$1.13
Supplies, labor	0.03
Roundhouse men	0.64
Total	$1.80

An Eastern road having 476 locomotives, handled at 31 roundhouses by 231 men, gives the following unit cost for 13,388 despatches monthly:

Handling	$0.79
Running repairs	2.83
Coal	8.32
Supplies	0.43
Water and water station	0.70
Total	$13.07

A Western line with 312 locomotives on 1,300 miles of line gives the following unit cost:

General	$0.70
Washout	0.27
Wiping	0.10
Cinders	0.13
Hostling	0.80
Coaling	0.35
Total	$2.35
Roundhouse repairs (heavy engines)	2.50
Total	$4.85

These engines average 125 miles per engine handled.

CHAPTER XII.

BRIDGES.

The Weight of Steel Bridges.—To compute the approximate cost of a steel bridge, it is first essential to estimate its weight. Formulas for estimating weights are given in this section, together with many examples of weights of bridges actually built, both for highway and for electric and steam railway purposes.

The following formulas, taken from Johnson's "Modern Framed Structures," give the weight of steel in trusses and floor-beams of highway and railway bridges.

For a highway bridge with a roadway 16 ft. wide, designed to carry 100 lbs. live load per sq. ft., use the following formula:

$$W = 12\,L + 150.$$

W = weight in lbs. per linear foot of bridge.

L = span in feet.

For bridges of less or greater width of roadway than 16 ft., subtract or add 15 lbs. per lin. ft. for each 2 ft. change in width.

For railroad bridges designed according to Cooper's E-50 loading, the weight of steel per lin. ft. of bridge is as follows:

For deck plate girders,

$$W = 12\,L + 150.$$

For through plate girders with beams and stringers,

$$W = 12\,L + 500.$$

For truss bridges,

$$W = 7\,L + 650.$$

The Weights of Steel Bridges for Highway, Railway and Electric Railway, Spans of 10-ft. to 300-ft.*.—In this issue we shall confine ourselves to the weights of standard bridges on the Northern Pacific Ry. and on the Santa Fe Ry., followed by Tyrrell's formulas for calculating the weights of bridges of moderate size.

Weights of Standard Bridges, A. T. & S. F. Ry.—These single track bridges are designed to carry a moving load of two 139-ton consolidation engines, followed by a train weighing 3,200 lbs. per lin. ft., according to specifications drawn in 1902.

**Engineering-Contracting*, Sept. 23, 1908.

Estimated Weights of Single Track Through Pin Truss Bridges; Atchison, Topeka & Santa Fe Ry.

Span c. to c. of pins. Ft.	Weight per span. Lbs.	Class.
100	193,700[1]	D
103	183,300	D
110	195,300	D
124	236,800	..
126	283,900[2]	D
128	244,300[3]	..
130	251,500	..
130	258,200[4]	..
134	263,200	C
149	295,500	C
149	347,500[5]	D
160	341,900	D
164	346,100	C
172	371,700	C
200*	499,500[6]	C
210†	490,400[7]	C
260	702,400[8]	C
300	914,500[9]	C

Note—All truss spans of 140 ft. and less have stiff bottom cords.
*Soft steel. †Medium steel.
[1], [2] and [5] stiff bottom chord carries floor; [3] 130-ft. span shortened; [4] span for 5° curve; [6] parallel chords; [7], [8], [9] chords not parallel.
C—Deep floors. D—Shallow floors.

Estimated Weight of Single Track Plate Girder Bridges; Atchison, Topeka & Santa Fe Ry.

	Deck Girders.		Through Girders.	
Span.	Class A. Lbs.	Class B. Lbs.	Class C. Lbs.	Class D. Lbs.
26 ft.	12,800	17,900	....	....
30 ft.	16,000	23,900	....	34,300
32 ft.	17,500	25,800	....	37,100
34 ft.	20,000	28,600	....	....
36 ft.	21,600	32,100	....	44,700
40 ft.	24,300	36,600	....	49,600
40 ft. 10° curve	24,600	......	....	....
42 ft.	26,000	39,200	....	....
44 ft.	28,300	36,000	....	....
48 ft.	35,500	45,000	....	63,400
48 ft. 5° curve	....	......	....	64,100
48 ft. 10° curve	....	......	....	64,400
50 ft.	36,900	49,800	....	68,600
52 ft.	40,900	50,000	....	73,000
54 ft.	42,500	53,500	....	76,800
58 ft.	....	58,500	....	....
60 ft.	51,500	62,400	80,200	90,400
60 ft. 5° curve	......	......	80,600	91,600
60 ft. 10° curve	......	......	81,100	92,600
62 ft.	......	......	....	93,600
64 ft.	56,100	66,800	82,200	97,700
64 ft. 5° curve	......	......	89,100	....
64 ft. 10° curve	......	......	89,700	....
66 ft.	58,600	......	....	....
70 ft.	68,800	83,300	105,000	112,000
70 ft. 5° curve	......	......	105,800	113,100
70 ft. 10° curve	......	......	106,300	113,900
75 ft.	78,500	94,800	113,200	129,200
75 ft. 5° curve	......	......	113,700	....
75 ft. 10° curve	......	......	114,000	....
80 ft.*	88,500	......	124,100	136,400
90 ft.*	110,600	......	159,900	172,200
100 ft.	133,600	......	....	....
105½ ft.	......	......	218,500	......

*Weights given for girders Class C and D are for round ended girders.

Classes *A* and *C* are designed in the most economic manner and are used wherever possible. Class *B* is for spans of the least depth consistent with good service. Class *D* is for spans with shallow floors.

Classes *B* and *D* are used only where it is less expensive to use these shallow bridges than to change the grade line. The tabular weight is the calculated weight plus 2½%. If the shipped weight is in excess of the tabular weight the excess is not paid for.

Weights of Standard Bridges, N. P. Ry.—In 1899 standard plans were made for Northern Pacific Ry. bridges. The assumed live load was two 146-ton locomotives, followed by 4,000 lbs. per lin. ft. of track. The following table gives the approximate weights of single track steel bridges, the weights being given closely enough for purposes of preliminary cost estimates.

Span in ft.	Weight in Lbs.
I Beam:	
20	10,000
30	20,000
Deck Plate Girders:	
25	13,000
35	20,000
40	25,000
50	37,000
60	50,000
70	63,000-73,000
80	96,000
90	113,000
100	133,000
Through Plate Girders:	
40	40,000
50	53,000
60	70,000
70	88,000-98,000
80	118,000
90	142,000
100	170,000
Deck Lattice:	
110	150,000
120	165,000
Through Lattice:	
110	174,000
120	215,000
Deck Pin Spans:	
130	202,000
140	220,000
150	244,000
160	264,000
170	297,000
180	330,000
190	360,000
200	392,000
Through Pin Spans:	
130	210,000
140	230,000
150	252,000
160	280,000
170	303,000
180	340,000
190	374,000
200	410,000

Formulas for Weights of Railway Bridges.—Mr. H. G. Tyrrell gives the following formulas: All weights (W) are per lineal foot of single track bridge for steel only; units 10,000 to 12,000 lbs. per sq. in. The live loads assumed are two engines weighing 100 tons each, and 4,000 lbs. per lin. ft. of track.

Deck plate girder bridge	$W = 100 + 9\ L$
Deck lattice girder bridge	$W = 100 + 8\ L$
Half through plate girder bridge with floor	$W = 100 + 12\ L$
Same with ties on shelf angle	$W = 200 + 8\frac{1}{2}\ L$
Same with trough floor	$W = 600 + 10\ L$
Riveted through truss bridge	$W = 400 + 6\ L$
Riveted deck truss bridge, ties on top chord	$W = 200 + 7\ L$
Pin through truss bridge	$W = 400 + 5\frac{1}{2}\ L$
Pin deck truss bridge with stringers	$W = 400 + 6\ L$
Pin deck truss bridge, ties on top chord	$W = 300 + 6\ L$

W = weight of steel, lbs. per lin. ft.
L = span in feet.

Railway Trestles.—Assumed loads same as above; weight of spans as above. Weight of bents and bracing is 9 lbs. per sq. ft. of side profile from ground to base of rail.

Mr. Tyrrell also gives the following formulas for the weights of single track railway bridges, for spans of 30 to 230 ft., designed according to Cooper's E 50 loading:

Deck plate girders, $W = 100 + 12\ L$.

Through plate girders, $W = 500 + 12\ L$.

Through truss spans, $W = 600 + 7\ L$.

W = weight in lbs. per lin. ft.

L = span in feet.

Add 90% for double track bridges.

Johnson's "Modern Framed Structures" gives the following formulas for the same loading:

Deck plate girders, $W = 150 + 12\ L$.

Through plate girders, $W = 500 + 12\ L$.

Through truss spans, $W = 650 + 7\ L$.

Cooper's E 50 loading provides for a train of two "consolidation engines" (177½ tons each, including tender), followed by a uniform live load of 5,000 lbs. per lin. ft.

Formulas for Weight of Electric Railway Bridges.—Mr. H. G. Tyrrell gives the following formulas for weight of single track electric railway bridges of 5 ft. to 200 ft. span. The weights include steel only, without safety stringers. The live load is assumed to cover the span from end to end. The details are figured for riveted joints.

I-beam spans of 5 to 20 ft., $W = 50 + 5\ L$.

For truss spans of 40 to 200 ft., loaded with 15-ton cars, or 1,000 lbs. per ft., $W = 200 + 0.8\ L$.

For truss spans of 20 to 180 ft., loaded with 30-ton cars, or 2,000 lbs. per lin. ft., $W = 250 + 1.5\ L$.

For deck plate girder spans, loaded with 2,000 lbs. per lin. ft., $W = 30 + 5\ L$.

W = weight of steel per lin. ft.

L = span in feet.

Electric railway trestles: Weights of spans same as above; weights of bents and bracing is 6 lbs. per sq. ft. of side profile from ground to base of rail.

Weights of Bridges, Ill. Central R. R.*—The Department of Bridges and Buildings of the Illinois Central Railroad has made standard designs of steel bridges of all ordinary spans, and has plotted the weights of steel in each type of bridge. From the curves thus plotted certain formulas have been derived for ascertaining the weight (W) of the steel in a bridge of any given span. It will be noted that these formulas are not like those found in text books.

Among the valuable diagrams of weights of standard bridges on the Illinois Central is one that gives the weight of draw (swing) bridges, from 75 to 450 ft. span. We do not recall ever having seen similar data for swing bridges. From the diagrams, we have prepared the tables that follow.

The formulas and tables are for class "R" loading, which is as follows:

"For all single track spans use equivalent uniform loads due to two 161.5-ton engines with a total wheel base of 104 ft., followed by a uniform train load of 4,600 lbs. per lineal foot of track.

"For double track spans, of either two or three trusses, and up to 150 ft. span, use equivalent uniform loads due to full engine and train loading as above on each track.

"For double track spans, of either two or three trusses, and over 150 ft. span, use equivalent uniform loads due to full engine and train loading on one track and uniform train load on the other.

"The weight of track will be assumed at 420 lbs. per ft. The weight of steel will be taken from the diagrams."

The weights of spans of intermediate length can be interpolated from the data given in the following tables:

WEIGHTS OF STEEL IN SINGLE TRACK DRAW BRIDGES.

Span, ft.	Without provision for ballast floors, lbs.	With provision for ballast floors, lbs.
75	80,000	100,000
100	120,000	150,000
125	170,000	215,000
150	230,000	280,000
175	295,000	360,000
200	365,000	450,000
225	450,000	550,000
250	545,000	660,000
275	655,000	800,000
300	785,000	970,000
350	1,100,000	2,320,000
400	1,440,000	1,690,000
450	1,800,000	2,090,000

Note.—Weights of intermediate spans of swing bridges may be interpolated. For weights of double track spans with three trusses add 85% to the above weights. The spans given in the above table are from c. to c. of end bearings.

**Engineering-Contracting*, June 7, 1909.

Weight of Steel in Single Track I-Beam Spans Without Ballast Floor.

($W = 3.5\,L^2 + 352\,L + 1215.$)

Span, ft.	Weight, lbs.
5	3,000
10	5,000
15	7,200
20	9,700
25	12,300
30	14,900
35	17,700

Weights of Steel in Single Track Deck Plate Girder Spans, Without Ballast Floor.

($W = 9.5\,L^2 + 200\,L + 450$ for spans less than 70 ft.)
($W = 28\,L^2 - 2{,}280\,L + 83{,}400$ for spans more than 70 ft.)

Span, ft.	Weight, lbs.
30	15,000
40	23,500
50	34,000
60	46.500
70	61,000
80	80,000
90	105,000
100	136,000

Weights of Steel in Single Track Deck Plate Girder Spans.

(Designed for future ballast floors.)

Span, ft.	Without I-Beams for future ballast floor.	With I-Beams for future ballast floor.
30	18,100	25,200
40	28,400	37,400
50	40,100	50,700
60	54,500	67,200
70	69,000	84,400
80	90,800	108,400
90	114,600	134,300
100	150,100	172,300

Weight of Steel in Single Track Through Plate Girder Spans, Without Ballast Floor.

($W = 1824\,L - 26{,}160$ for spans less than 76 ft.)
($W = 75\,L^2 - 9{,}927\,L + 433{,}740$ for spans more than 76 ft.)

Span, ft.	Weight, lbs.
30	28,500
40	46,600
50	64,600
60	82,700
70	100,700
80	120,000
85	131,800
90	147,300
100	190,500

WEIGHT OF STEEL IN SINGLE TRACK THROUGH PLATE GIRDER SPANS, DESIGNED FOR FUTURE BALLAST FLOOR.

Span, ft.	Weight, lbs.
40	64,400
50	81,200
60	103,800
70	128,000
80	154,100
90	189,600
100	224,800

WEIGHT OF STEEL IN SINGLE TRACK THROUGH PIN SPANS, WITHOUT BALLAST FLOOR.

($W = 7.9\,L^2 + 870\,L + 11{,}500.$)

Span, ft.	Weight, lbs.
110	203,000
120	230,000
140	288,000
160	353,000
180	424,000
200	500,000
220	585,000
240	675,000
260	772,000
280	874,000
300	984,000
320	1,100,000
340	1,221,000
360	1,349,000
380	1,481,000
400	1,621,000

WEIGHTS OF STEEL IN SINGLE TRACK THROUGH PIN SPAN BRIDGES, DESIGNED FOR FUTURE BALLAST FLOORS.

Span, ft.	Weight, lbs.
100	220,000
120	290,000
140	370,000
160	455,000
180	550,000
200	650,000
220	770,000
240	900,000
250	972,000

WEIGHT OF STEEL IN DOUBLE TRACK THROUGH PLATE GIRDER SPANS (2 LIGHT AND 1 HEAVY GIRDER), WITHOUT BALLAST FLOOR.

($W = 4\,L^2 + 2{,}980\,L - 44{,}000$ for spans 30 to 80 ft.)
($W = 68\,L^2 - 7{,}100\,L + 352{,}800$ for spans 80 to 100 ft.)

Span, ft.	Weight, lbs.
30	49,000
40	82,000
50	115,000
60	149,000
70	184,000
80	220,000
90	264,000
100	324,500

WEIGHT OF STEEL IN DOUBLE TRACK THROUGH PIN SPANS (2 LIGHT AND 1 HEAVY TRUSS), WITHOUT BALLAST FLOOR.

$$(W = 14.38\,L^2 + 1{,}583\,L + 20{,}900.)$$

Span, ft.	Weight, lbs.
110	370,000
120	418,000
140	524,000
160	640,000
180	771,000
200	911,000
220	1,065,000
240	1,230,000
260	1,404,000
280	1,593,000
300	1,790,000
320	2,000,000
340	2,222,000
360	2,455,000
380	2,700,000
400	2,955,000

Note.—If the bridge is designed with only two trusses, instead of three, add 82% to the weights given in the above table.

WEIGHT OF STEEL IN DOUBLE TRACK THROUGH PLATE GIRDER SPANS (2 LIGHT AND 1 HEAVY GIRDER), DESIGNED FOR FUTURE BALLAST FLOORS.

Span, ft.	Weight, lbs.
40	117,300
50	148,900
60	187,700
70	230,700
80	282,100
90	340,300
100	402,100

Formulas for Weight of Highway Bridges.—Mr. H. G. Tyrrell gives the following formulas for the weight of steel in highway truss bridges:

With sidewalks, $W = 2.8 + \dfrac{L}{11.3}$

Without sidewalks, $W = 5 + \dfrac{L}{9.5}$

L = length of span in feet.

W = weight of steel per sq. ft. of floor, including both carriageway and walk. The weight includes bracing and shoe plates, but not joists or floor. These formulas were based upon designs of through truss spans from 50 to 150 ft., for roadways ranging from 14 to 20 ft. wide. The trusses are riveted. The live load assumed was 80 lbs. per sq. ft. for trusses and 100 lbs. per sq. ft. floor beams, or a 6-ton wagon. These bridges have timber joists and a floor composed of two layers of plank.

The following formulas are for plate girder highway bridges having 16 to 24 ft. roadway and 20 to 80 ft. span, loading same as above.

Through plate girder $W = 3 + \frac{L}{4.25}$

Deck plate girder, $W = 2.1 + \frac{L}{5}$

W = weight of steel per sq. ft. and does not include the timber stringers and plank floor.

For highway bridges with solid floors (assumed dead weight of floor, 150 lbs. per sq. ft.), Mr. Tyrrell gives the following formulas:

Deck plate girder bridges, $W = 3 + \frac{L}{2.6}$

Half through girder bridges, $W = 3 + \frac{L}{2.4}$

Truss bridges, $W = 3 + \frac{L}{4}$

Weight of a 465-ft. Span Highway Bridge.*—The longest highway truss span in America was built in 1901 across the Miami River at New Baltimore, Ohio. It has a span of 465 ft. c. to c. of end pins, and a depth of 66 ft. at the middle. The pin connected trusses are 25 ft. apart in the clear. The bridge is designed for a live load of 2,600 lbs. per lin. ft., with a live load of 100 lbs. sq. ft. on the floor system and a 6-ton road roller as a concentrated load. The floor system consists of plate girder floor beams, I-beam stringers, and 2½-in. plank floor. There is no sidewalk and no street railway track. The weight of the bridge is 1,000,000 lbs., or 2,150 lbs. per lin. ft. or 86 lbs. per sq. ft.

Weight of a 406-ft. Span Highway Bridge.*—A very long highway truss span was built in 1899 across the Miami River at Hamilton, Ohio. The span is 406 ft. c. to c. of end pins. The trusses are 50 ft. deep at the middle and spaced 26½ ft. c. to c. The roadway is 22 ft. wide, and the two cantilever sidewalks are 6 ft. wide each, making a total floor width of 34 ft. The trusses are calculated for a dead load of 5,000 lbs. per lin. ft. of span and a live load of 2,720 lbs. per lin. ft. of span, or 80 lbs. per sp. ft. of floor. The floor system is calculated for a 20-ton roller on two axles 12 ft. apart, or a 16-ton electric car. The floor of the roadway is asphalt blocks on concrete laid on buckle plates, supported by I-beam stringers. The sidewalks are concrete slabs. The total weight of steel in the bridge is 1,300,000 lbs.

Weight and Cost of a Highway Bridge, 120-ft. Spans.*—A steel highway bridge was built in 1905 across the Wabash River at Terre Haute, Ind. It is 812 ft. long between abutments, and consists of 6 spans of 120 ft. each and one 75-ft. span in the center. The roadway is 50 ft. wide, and there is an 8-ft. cantilever sidewalk

*_Engineering-Contracting,_ Oct. 7, 1908.

on each side, making a total floor width of 66 ft. It is a deck bridge, and each span has two riveted trusses 53 ft. c. to c., with three intermediate plate girders. The roadway is paved with brick. The total weight of steel in the bridge is 4,144,000 lbs. including 88,000 lbs. of street car rails. There are 2,330 cu. yds. of concrete in the two abutments and 3,900 cu. yds. in the six piers; there are 718 piles. The piers average 50 ft. high. The substructure cost $78,700, and the superstructure cost $192,500, a total of $271,200, by contract, including the removal of an old bridge and the building of a temporary bridge, which is equivalent to $334 per lin. ft., or $5 per sq. ft. of floor area.

Weight of a 450-ft. Span Highway Swing Bridge.*—A highway swing span of unusual length was built across the Connecticut River in 1896. The bridge is 450 ft. long. The trusses are 26 ft. c. to c., providing for one line of electric cars and two lines of carriages. The floor is designed to carry 100 lbs. per sq. ft., 14 ton electric cars or a 10 ton wagon. The trusses are designed to carry a live load of 1,500 lbs. per lin. ft. for chords and 2,000 lbs. for web. The floor consists of 4x14-in. yellow pine stringers spaced 2½ ft. apart, supporting two layers of plank, 3 in. and 2 in., respectively. The stringers for the car track are 15-in. steel beams weighing 42 lbs. per ft. There are 22 panels, depth 21 to 55 ft. The turntable is rim bearing. The drum is 4 ft. deep and 31 ft. diameter. Three 25-HP. motors are used, one for turning and two for blocking up the ends. An extra motor is provided. To open takes the motor 30 seconds. Working on 10-ft. levers the bridge is turned by four men in 8 minutes. The total weight of drawbridge superstructure, including drum and flooring, is 1,380,000 lbs.

Weight of a 520-ft. Double Track Swing Bridge.*—The longest swing span in the world is the Interstate bridge. It is a double track railway draw bridge, built in 1908, across the Missouri River at East Omaha, Neb. The trusses were designed to carry a live load of 11,180 lbs. per lin. ft. of bridge. This heavy load was allowed in case it should be desired to provide a cantilevered roadway and sidewalk 16 ft. wide on the outside of each truss. The weight of this 520-ft. draw span is 3,900,000 lbs. There were also 9 plate girder 60-ft. spans in the approach, having a total length of 575 ft., and a total weight of 1,773,000 lbs. The pivot pier was sunk to bed rock, a depth of 120 ft. below low water, by open dredging inside a steel cylinder.

The following are the quantities in the substructure:

	Cu. Yds.
Mass in cribs and pneumatic caissons of 2 piers 80 ft. deep..	4,180
Mass in base of pivot pier.............................	5,390
Mass in bases of 8-pile piers and 2 abutments.............	2,330
Masonry in shafts of 4 large piers......................	2,135
Concrete in shafts of 8 shore piers and 2 abutments........	1,550
	Lin. Ft.
Piling below bases of 8 shore piers and abutments..........	19,900
	Lbs.
Steel in pivot pier "well" or open caisson................	580,000

*Engineering-Contracting, Oct. 7, 1908.

The "4 large piers" above mentioned are the pivot pier of the draw span and its two rest piers, and a third rest pier for an old existing draw span.

The contract price for this 520-ft. swing bridge and approaches was $600,000.

Weight of a 450-ft. Double Track Swing Bridge.*—A double track draw bridge, with 5 approach (single track) spans, was built in 1905 across the Tennessee River for the Illinois Central Ry., to replace a lighter steel bridge built 17 years previously. The draw bridge is 450 ft. long, and about 25 ft. c. to c. of trusses. Three of the approach spans are 300 ft. each, and two are 150 ft. each, and are all single track, the trusses being 17½ ft. c. to c. The weights of steel in these spans are as follows:

	Lbs.
1 double track draw span (450 ft.) and turntable	2,576,000
3 single track spans, 300 ft. each	4,074,000
2 single track spans, 150 ft. each	764,000
Total	7,414,000

The price for the draw span was 4.45 cents per lb. ready to assemble; and the price for the pin connected truss spans was 3.64 cents per lb. The cost by contract for erection was $90,000, which is about 1¼ cents per lb. The pivot pier is 62 ft. high, and 47 ft. diameter. It contains 873 cu. yds. of concrete footing and 1,356 cu. yds. of concrete above the footing, or a total of 2,229 cu. yds., and 16,200 lbs. of reinforcing rods. It rests on 805 piles.

Weight of a 438-ft. Single Track Swing Bridge.*—As a part of the single track bridge, built in 1899 over the Mississippi River, for the Davenport, Rock Island and Northwestern Ry., there are one 361-ft., three 296-ft., and three 200-ft. pin-connected truss spans, beside a 438-swing span which is described subsequently. The trusses are designed for Cooper's Class E 35-train load, and the floor system for Class E 40. The trusses are 18½ ft. c. to c. The weights of each span is as follows:

	Lbs.
438-ft. swing span (including machinery)	1,400,600
361-ft. span (c. to c. end pins)	1,039,100
296-ft. span (c. to c. of end pins)	742,400
200-ft. span (c. to c. of end pins)	410,000

Weight and Cost of a 334-ft. Four Track Swing Bridge.*—A four track swing bridge was built in 1900 across the Chicago Drainage canal at West 46th street, Chicago, for the Chicago & Western Indiana R. R. It is unique among four track swing bridges in that it has two trusses instead of three. By this arrangement the center pier is only 43 ft. diameter, thus saving about 20 ft. of length over a three-truss bridge that gives the same clear waterway. The bridge is 334 ft. long c. to c. of end bearings. It is 29¼ ft. c. to c. of trusses, two of the tracks being supported on cantilever floor beams outside the trusses. The total width is 57 ft. The live load, continuous girder of four supports, is 4,980 lbs. per lin. ft.

**Engineering-Contracting*, Oct. 7, 1908.

on the adjacent inside track, 4,200 lbs. per lin. ft. on the adjacent outside track, with no load on the distant outside track.

The weight of steel and iron is 2,692,000 lbs., exclusive of the operating machinery.

The pier is octagonal, 44 ft. diameter, over coping, masonry shell 7 ft. thick, filled with earth inside, is 30 ft. high and rests on clay. The substructure cost $51,353, the contract prices being: Excavation, 51 cts.; concrete, $7.30; stone masonry, $13.35 per cu. yd. The superstructure cost $131,393, or nearly 4.9 cts. per lb. including the floor. The total cost was $182,746, or $547 per lin. ft. of bridge, or $137 per lin. ft. of track.

Weight of a 231ft. Single Track Swing Bridge.*—A single track swing brige was built across the St. Joseph River, for the Pere Marquette Ry., to replace an older span having become too light for modern locomotives. The bridge is 231 ft. c. to c. of end floor beams, and 17 ft. 8 ins. c. to c. of trusses. It was designed for Cooper's Class E loading, and its weight is 600,000 lbs. It is operated by a 30-HP. gasoline engine which opens or closes it in one minute.

Weight of a 216-ft. Double Track Swing Bridge.—A double track swing bridge was built in 1899 across Kinnickinnic River, near Milwaukee, for the Chicago & Northwestern Ry., to replace a single track pin-connected bridge built 19 years previously. It is a riveted lattice truss draw bridge, 216 ft. long, trusses 27 ft. apart in the clear, and designed for a load of two 131½-ton engines followed by a train weighing 4,000 lbs. per lin. ft. on each track. Its weight is 1,200,000 lbs. including track, machinery, etc.

Weight and Cost of a 1,504-ft. (3 Spans) Cantilever Double Track Bridge.*—The longest cantilever railway bridge in America is a bridge finished in 1903 across the Monongahela River at Pittsburg, for the Wabash R. R. It is 1,504 ft. long exclusive of approaches. The channel span is 812 ft. c. to c. of piers, and each of the shore spans is 346 ft. c. to c. of piers. The steel towers are 126 ft. high, and the depth of the suspended span is 60 ft. The live load consists of two consolidation engines (on each track) followed by a train load of 4,500 lbs. per lin. ft. The weight of the superstructure is 14,000,000 lbs., or 9,300 lbs. per lin. ft. The cost of substructure and superstructure was $800,000, or $533 per lin. ft.

The four piers were sunk to rock by the pneumatic caisson process. The height of the four piers averaged 110 ft., of which 35 ft. is below low water.

Weight and Cost of a 1,296-ft. (3 Spans) Cantilever Double Track Bridge.*—A double track cantilever bridge was finished in 1903 across the Ohio River, at Mingo Junction, Ohio, for the Wabash R. R. It is 1,296 ft. long exclusive of approaches. The channel span is 700 ft. and each of the two shore spans is 298 ft. c. to c. of piers. The steel towers are 109 ft. high, and the depth of the suspended span is 51¾ ft. Two of the piers have caisson founda-

**Engineering-Contracting*, Oct. 7, 1908.

tions and are 115 ft. high, 25 ft. of which is below low water level. One pier is 100 ft. high, of which only 10 ft. is below low water. There is an abutment (instead of a fourth pier) 40 ft. high. The weight of the superstructure is 12,000,000 lbs. exclusive of approaches. The cost of the substructure and superstructure was $750,000, or $577 per lin. ft.

Weight and Cost of a 2,750-ft. (5 Spans) Cantilever Double Track Bridge.*—A double track cantilever bridge was finished in 1905 across the Mississippi River at Thebes, Ill., for the Illinois Central and other railways. It has a length of 2,750 ft. (exclusive of concrete approaches) and consists of 5 spans: one 671 ft., two 521 ft., and two 518 ft., measured center to center of piers. The steel superstructure weighs 24,000,000 lbs., and cost $1,400,000, and the substructure cost $600,000, a total of $2,000,000, which is $800 per lin. ft. The piers have an average height of about 115 ft. from the cutting edge of the caisson to the top of the pier, and the water averages 20 ft. deep when low. One pier was sunk to a depth of 40 ft. below low water. There is a double track concrete viaduct approach on each side, having a total length of about 1,200 ft., consisting of 65-ft. arches. The height of this viaduct is about 100 ft., and its cost was $300,000, or about $250 per lin. ft.

Weight of a 1,380-ft. (3 Spans) Cantilever Highway Bridge.*—A cantilever highway bridge was finished in 1903 across the Ohio River at Marietta, Ohio, for the Ohio River Bridge and Ferry Co. Its length is 1,380 ft. exclusive of two approach spans of 220 ft. each and a plate girder viaduct 640 ft. long, but with these the total length is 2,460 ft. The width is 28 ft. c. to c. of trusses, or 25 ft. clear width of roadway including a 4½-ft. sidewalk. The live load for the trusses was assumed at 60 lbs. per sq. ft.; and for the floor system it was assumed at 80 lbs. per sq. ft. or a steam roller of 15 tons. The cantilever is of peculiar design, due to necessity of providing two channels and of placing one of the piers in a shallow part of the river. The length of the main channel span is 650 ft.; the south anchorage span is 600 ft.; the north anchorage span is 130 ft.; all c. to c. of piers. The trusses are pin connected. The floor system consists of plate girder floor beams, timber stringers, and plank floor. The weight is 4,800,000 lbs., including the approach spans and the viaduct.

Weight and Cost of a Scherzer Highway Lift Bridge.†—A Scherzer rolling lift highway bridge was built in 1897 across the Chicago River at Halsted street. Length of movable part, 176 ft., divided into two leaves 38 ft. long, giving a clear span of 121 ft. between faces of abutments and 109 ft. between protection piles; length of each of the two anchor spans, 50 ft.; total length 276 ft.; width of carriageway, 34 ft. c. to c. of trusses; width of each sidewalk, 7¼ ft. center of truss to center of hand rail; total width, 50 ft. The bridge was designed to carry 100 lbs. per sq. ft., or an 18-ton motor car followed by trailers weighing 15 tons, each on an 8 ft. wheel

---

**Engineering-Contracting*, Oct. 7, 1908.

†*Engineering-Contracting*, Dec. 2, 1908.

base and having 37 ft. length. The weight of superstructure, including the 50 ft. approach spans, is 820 tons, of which 300 tons is counterweights. The weight of the machinery is 70 tons. Each leaf is operated by a 50 HP. motor. It requires an average of 40 HP. to open each leaf, and about the same for closing, the time required being ¾ min. to open and the same to close. The cost of the bridge to the city was:

Substructure	$ 34,500
Superstructure	55,400
Machinery	13,560
Electrical equipment	5,400
Engineering, inspection, temporary foot bridge and incidentals	14,740
Total	$123,600

Cost of a Scherzer Highway Lift Bridge.*—In 1894 a Scherzer rolling lift highway bridge was built across the Chicago River, on Van Buren street, Chicago. The span is 115 ft. c. to c. of bearings, giving a clear channel of 109 ft. It has 2 roadways of 21 ft. c. to c. of trusses, and 2 sidewalks of 8½ ft. each. The piers are of concrete and sandstone masonry resting on piles. Each leaf of the bridge has 3 trusses, and is counterweighted with 129 tons of cast iron. The floor is plank, resting on steel I-beams. Two 50 HP. motors operate each leaf. Tests have shown that it requires an average of 60 HP. to raise one leaf at a time, and 96 HP. to raise both sides simultaneously.

Exclusive of engineering and inspection, the bridge cost:

Superstructure	$ 73,100
Substructure	79,600
Electric equipment and machinery	11,150
Total	$163,850

Weight of a Scherzer Railway Lift Bridge.*—A double track bascule bridge of the Scherzer type was built in 1904 to replace a draw bridge built 17 years previously, the draw bridge having become too light for the traffic on the Central R. R. of New Jersey. The bridge is part of the Newark Bay crossing. The bridge consists of two lift spans, back to back, across two separate channels. Each of these spans is 120 ft. c. to c. to center of piers, or 110 ft. between piers; but, due to the skew, the clear channel width is only 85 ft. Each span weighs 2,000,000 lbs., about half of which is in the cast iron counterweight, leaving 1,000,000 in the span alone.

Weight of a Scherzer Railway Lift Bridge.*—A rolling lift bridge of the Scherzer type was built in 1899, at the Fort Point Channel, Boston, for the New York, New Haven and Hartford Railroad. It is a skew bridge, the skew being 42°. One truss is 113 ft. long, the other being 84 ft., and the distance from center to center of chords is 27 ft. The weight of this double track bascule bridge is 381,200 lbs. The counterweights weigh 3,100 lbs. The time to operate the bridge one way is 35 secs. with a 60 HP. motor.

**Engineering-Contracting*, Dec. 2, 1908.

Cost of a Page Highway Lift Bridge.*—A trunnion bascule highway bridge was built in 1901 across the Chicago River at Ashland avenue. The bridge is of the Page type and consists of two leaves, 168 ft. c. to c. of trunnions. The bridge is 258 ft. long, and has a clear waterway of 140 ft. between fender piles. The trusses are 40 ft. c. to c. carrying a 36-ft. clear roadway with two 8-ft. cantilever sidewalks, making a total of 52 ft. of floor width. The bridge is designed for a live load of 100 lbs. per sq. ft. for the roadway and 80 lbs. for the sidewalks; concentrated load 20 tons on two axles 12 ft. c. to c. The weight of steel in each leaf is 340,000 lbs. There are about 620,000 lbs. of cast iron for counterweights of each leaf. The substructure required the following quantities:

Excavation	6,500 cu. yds.
Concrete	2,820 cu. yds.
Sheet piling and bracing	250,000 ft. B. M.
Timber in protection work and dock	23,500 ft. B. M.
Piles in protection work and dock	7,300 lin. ft.
Piles in coffer dam	2,100 lin. ft.

The contract price was:

Substructure	$ 35,540
Superstructure	91,200
Total	$126,740

Cost of a Page Railway Lift Bridge.*—A double track single-leaf bascule bridge of the Page type was built in 1907 over the Chicago River by the Chicago & Alton Ry. It has a span of 150 ft., and there is an approach span of 64 ft. The superstructure, including electrical equipment for operation, cost $115,000. The substructure, including the removal of an old pivot pier and some dredging of the channel, cost $50,000, making a total cost of $165,000. The substructure contained 3,200 cu. yds. of concrete.

Cost of a Trunnion Bascule (Lift) Bridge.*—A trunnion bascule highway bridge was built at Clybourn Place, Chicago, in 1902, according to designs of John Ericson, City Engineer. The bridge is a fixed center, double leaf, counterbalanced bascule, 128 ft. c. to c. of pivot bearings, and 120 ft. c. to c. of piers, with a clear channel of 100 ft. between the guard piles that protect the piers. The length over all is 180 ft. Each leaf has three through trusses, 21 ft. c. to c., and the total width of the bridge is 60 ft., the sidewalks being carried on 9-ft. cantilever brackets. The motive power is two 38 HP. motors. The bed of the river is about 40 ft. below the lower chord of the bridge, and the water is 23 ft. deep. The substructure is of concrete resting on piles. The contract price was $69,000 for substructure and $86,000 for superstructure, or a total of $155,000. The weight of each leaf is 640,000 lbs. including structural steel, cast iron rack, timber and counterweights. This is equivalent to nearly $1,300 per lin. ft. of span between piers, or $860 per lin. ft. of total length.

Cost of a Trunnion Bascule (Lift) Bridge.*—A trunnion bascule highway bridge was built in 1903 at Northwestern avenue, Chi-

**Engineering-Contracting,* Dec. 2, 1908.

cago. It consists of two leaves, and the span between centers of trunnions is 205 ft., while the span between abutments is 190 ft., and the clear width of the channel is 165 ft. between the timber protection works. There are three lines of trusses 21 ft. c. to c., and 9 ft. cantilever sidewalks, making a total width of 60 ft. There are two approach spans, one of 75 ft. and one of 17 ft. The total length of the bridge is 361 ft., and it contains 2,180,000 lbs. of structural steel, 1,400,000 lbs. of counterweight pig and cast iron, and 200,000 lbs. of machinery. The substructure consists of 4,500 cu. yds. of concrete and 300 cu. yds. of rubble curb walls for the approaches. The contract price for the substructure was $88,200, and $208,500 for the superstructure, a total of $296,700.

Weight of an 840 ft. Span Arch Bridge.*—The Niagara Falls and Clifton steel arch bridge was built in 1895-1898. It consists of a main span of 840 ft. and two end spans, one of 190 ft. and the other of 210 ft., giving a total length of 1,240 ft. The main arch springs from the solid rock. The arch is two-hinged, parabolic, and has a rise of 137 ft. The end spans are pin-connected, inverted bow string trusses. The bridge carries on one level two lines of trolley car tracks, two carriageways and two sidewalks, having a total width of 46 ft. There are 1,637 cu. yds. of masonry in the substructure. The materials used in the main span were as follows:

	Lbs.
Two-arch trusses, not including laterals	1,673,356
Laterals of arch	383,522
Bents, including lateral bracing	450,577
Longitudinal bracing	150,705
Skewbacks and shoes	226,634
Floor system	766,287
Total	3,651,081
In addition there were:	
New York end span	344,862
Canadian end span	371,733
Hand rail and floor fastenings	83,048
Miscellaneous (field rivets, etc.)	81,323
Grand total	4,532,047

There were 246,000 ft. B. M. of timber in the permanent flooring.

Weight and Cost of a 195 ft. Span Arch Bridge.*—A steel arch highway bridge was built in 1900 across Nine-Mile Run, at Pittsburg. The total length is 444 ft. The carriageway is 36 ft. wide, on each side of which is 6½-ft. cantilever sidewalk, making a total width of 49 ft. of floor. It consists of a steel arch span, 195 ft. c. to c. of pins, and a steel viaduct approach of five 24-ft. plate girder spans on each side of the arch span. The arch span is a pair of three-hinge plate girders. The sidewalks and carriageway are made of buckle plates and concrete, the carriageway being paved with asphalt. The arch has a rise of 59 ft.; and, as the ground rises rapidly from the skewbacks toward each end of the bridge, the average height of the viaduct approaches is about half this rise, or 30 ft.

*_Engineering-Contracting_, Dec. 2, 1908.

The materials were as follows:

Structural steel (lbs.)	1,457,000
Railing, 889 lin. ft. (lbs.)	60,000
Stone Masonry (cu. yds.)	1,410
Concrete (cu. yds.)	287
Paving on roadway (sq. yds.)	1,800
Paving on sidewalk (sq. ft.)	5,500
Curb (lin. ft.)	890

The total contract cost was $86,534, including $535 for mill, shop and field inspection of the steel, or 70 cts. per ton for inspection.

This is equivalent to $195 per lin. ft., or $4 per sq. ft. of floor.

Weight of a 207 ft. Span Arch Bridge.*—A single track, three-hinged steel arch bridge was finished in 1903 across the Menominee River, Michigan, for the Chicago, Milwaukee & St. Paul Ry., replacing a steel bridge built 17 years previously, which had grown too light for the traffic. The bridge is 355 ft. long, consisting of a three-hinged arch of 207 ft. span and four plate girder approach spans of 39½ ft. each. The trusses are 22 ft. c. to c. The arch has a rise of 52 ft. The bridge is designed according to Cooper's specifications for a live load of two consolidation Class E-50 locomotives and 7,000 lbs. per lin. ft. behind the engines. The weight of steel in the arch span is 480,000 lbs., and in the approach spans it is 150,000 lbs.

Weight and Cost of a 440 ft. Span Arch Bridge.*—A steel highway bridge was built in 1906 in Pittsburg. It is known as the Oakland Bridge. It is 800 ft. long and has a roadway 20 ft. wide, with a 7 ft. cantilever sidewalk on each side. It consists of an arch having a span 440 ft. and a rise of 70 ft., and a steel viaduct approach at each end of the arch, the spans of the approach girders being 30 to 40 ft. each. The arch span consists of two lattice girder arch ribs, abutting on concrete abutments built on the solid rock. The arch is not hinged. The cost of this bridge was $138,000, which is equivalent to $172 per lin. ft., or $4.50 per sq. ft. of floor area.

Cost of Steel Arch Bridge.*—A steel highway bridge was built in 1906 across the Potomac River, at Washington, D. C. The bridge is 1,000 ft. long between abutments, and consists of 6 three-hinged arch spans of 129 ft. each, and one two-leaf bascule span of 103 ft. Each of the arch spans has six plate girder ribs. The bridge is 48 ft. wide between handrails, having two 6½ ft. sidewalks and a 35 ft. roadway. The rise of the arches is 14 ft., and the height of the piers averages about 65 ft. to the spring line. The concrete piers rest on pile foundations. The site of each pier had to be dredged before driving the piles. The low water surface is about 10 ft. below the spring line of the arches. The bridge cost $375,000, or $375 per lin. ft., or $7.80 per sq. ft.

Weight of the Burlington Bridge of the C., B. & Q.†—In 1890 a double track steel railway bridge was built across the Mississippi River, at Burlington, for the C., B. & Q. R. R., to replace a single

**Engineering-Contracting,* Dec. 2, 1908.

†*Engineering-Contracting,* Nov. 4, 1908.

track iron bridge built 22 years before. The 6 spans of 250 ft. each, weighed 3,340 lbs. per lin. ft. The draw span of 363 ft. weighed 3,980 lbs. per lin. ft. The bridge was designed to carry a moving load of 6,000 lbs. per ft. of double track structure (3,000 lbs. per ft. of single track), this load being increased 50% in estimating the variable effect of a moving load.

The cost of engineering was 5% of the total cost of piers and superstructure.

Weight of a Double Track Draw Bridge, 195 ft. Span.—A double track swing bridge (through riveted truss) was built in 1901 across the Hackensack River, N. J., for the D., L. & W. Ry. Its weight is 1,206,000 lbs. and its length is 195 ft.

Weight of a 533 ft. Span Railway Bridge and of a 323 ft. Draw Span Across the Delaware.—A double track railway bridge was built in 1896 across the Delaware River, at Bridesburg, for the Pennsylvania and N. J. R. R. Co. There are three spans of 533 ft. each, and a draw span of 323 ft. The weight of steel in each of the three 533 ft. spans is 4,182,000 lbs.

The weight of the steel in the draw span with riveted work is 1,505,000 lbs., and the weight of the machinery is 356,000 lbs., total 1,861,000 lbs.

A steel traveler was used to erect the bridge. The traveler was 110 ft. high, 46 ft. wide at the bottom and 81 ft. wide on top. Its weight was 292,000 lbs. without trucks.

Weight of a Highway Cantilever Bridge, 1,024 ft. Long.—Mr Gustave Kaufman gives the following data relative to the weight of a highway bridge at Cincinnati, built in 1890.

The cantilever bridge has a span of 520 ft. c. to c. of piers, and the shore arms of the cantilever are each 252 ft. long, making a total length of 1,024 ft. This does not include several approach spans on each side.

The weight of metal is as follows:

	Lbs.
Shore arms of cantilever	1,376,978
River arms of cantilever	691,360
Suspended span (208 ft.)	335,185
Total	2,403,523

It required ⅓ gal. of paint per ton of metal for two coats.

The bridge trusses were designed for a live load of 80 lbs. per sq. ft. The stringers and floor beams were designed for a live load of 100 lbs. per sq. ft., or a 15-ton steam roller. The roadway consists of 6 lines of iron stringers riveted to iron floor beams, and covered with cross timbers, spaced 30 ins. c. to c., to which are spiked two layers of oak flooring having a total thickness of 5¼ ins. The roadway is 2 ft. wide in the clear, and the sidewalks (which are on brackets outside of the trusses) are each 7½ ft. wide in the clear.

Estimating Cost of a Steel Bridge Erection.—The cost of erecting steel bridges should be separated into two main items: (1)

cost of falsework, and (2) cost of erecting the steel. Usually, however, engineers who have published cost data have unfortunately lumped these two items together.

The cost of falsework for any given bridge, and of a traveler of given design, can be estimated from the data given in the section on Timberwork, and from data in the following pages.

It should be remembered that railway plate girder bridges are usually erected with little or no falsework. Railway plate girders up to 80-ft. span, and occasionally up to 120-ft. span, are shipped as single pieces. Short girders are skidded flat into position from the car and then turned on edge. Long girders may be lifted from the cars by gallows frames and lowered to position.

Swing bridges are erected on the pile fender or guard pier, which serves as the falsework. This makes the cost of erection much less than for truss bridges for which falsework must be built.

Steel viaducts are erected with travelers, so that no falsework is required.

The cost of materials and of labor on steel bridges should be recorded in terms of the pound of steel as the unit, or in terms of the ton of 2,000 lbs.

Cost Per Lin. Ft. and Per Sq. Ft.—It is customary to state the cost of railway bridges in terms of the lineal foot of span, while the cost of highway bridges is preferably reduced to the square foot of floor area as the unit. However, it should be remembered that, in either case, the unit cost increases rapidly as the span increases.

The cost of viaducts is often given in terms of the square foot of profile area; but care should be taken to state whether the total profile area is estimated below the base of the railway rail, or below the top of the towers.

Most Economical Span.—Mr. J. A. L. Waddell, M. Am. Soc. C. E., was, I believe, the first to enunciate the following theory (in 1890): "For any crossing, the greatest economy will be attained when the cost per lineal foot of the substructure is equal to the cost per lineal foot of the trusses and lateral systems." Note that the cost of the floor system, being practically independent of the length of the span, does not enter into this generalization.

The following is the demonstration of this theory: Assume a bridge crossing of indefinite length, with the depth to bedrock constant. Let

$S =$ cost per lin. ft. of substructure.
$T =$ cost per lin. ft. of trusses and laterals.
$F =$ cost per lin. ft. of floor system.
$Y =$ cost per lin. ft. of entire bridge.
$L =$ length of each span.
$Y = S + T + F.$

Assuming that slight changes in L will not materially affect the size of the piers, S will vary inversely as L, hence

$S = \dfrac{K}{L}$, K being a constant.

But, for slight changes of L, T varies nearly directly as L, hence $T = C L$, C being a constant. Since F is practically a constant, being a function of panel length and not of span length, we have

$$Y = \frac{K}{L} + C L + F,$$

in which Y is to be made a minimum. Differentiating we have $d Y = \frac{-K d L}{L^2} + C d L$, whence, by putting $\frac{d Y}{d L} = O$, we have $\frac{-S}{L} + \frac{T}{L} = O$, or $S = T$.

A further differentiation shows that the result corresponds to a minimum. Although no bridge is indefinite in length, and although ledge rock usually is found at different depths, still this same principle may be applied to each pier and the two spans that it helps to support, by making the cost of the pier equal to one-half the total cost of the trusses and laterals of the two spans.

The principle obviously applies to trestles, viaducts and elevated roads.

In an ordinary viaduct, consisting of alternate spans and towers, the cost of all the girders in two spans (one span being over the tower), plus the cost of the longitudinal bracing of one tower, should equal the cost of the two bents of the tower plus the cost of their masonry pedestals.

In an elevated railway, the cost of the stringers or girders of one span should equal the cost of one bent, including its pedestals.

The Life of Steel Railway Bridges.*—Considering the economic importance of the subject, it is astonishing that no tabulated statistics as to the life of American steel railway bridges can be found in print.

Bridge engineers are accustomed to denominate wooden bridges as "temporary," while they call steel bridges "permanent." The annual reports of railway managers to stockholders contain these expressions, and there is a general acquiescence in the propriety of their application. But the facts are that steel railway bridges are so far from being permanent that they, too, should be classed as temporary.

We must not be misunderstood as decrying the lasting qualities of steel itself, for there is abundant evidence that iron and steel are exceedingly lasting under certain conditions. Let us illustrate.

The "first iron railway bridge" was built in 1823, for the Stockton & Darlington Ry., at West Auckland, England, and was not removed until 1903, after 80 years of service. This bridge is illustrated and described in the "Railroad Gazette," July 8, 1904, p. 125. The bridge was, in fact, an iron trestle with cast iron posts and four iron spans of 12 ft. 8 ins. each. The spans consisted of double arch members of wrought iron united by cast iron struts.

**Engineering-Contracting*, Oct. 7, 1908.

As is well known, the life of an iron or street railway bridge is not limited by the durability of the bridge, but by its ability to withstand the steadily increasing loads imposed upon it.

The average age of the 1,000 locomotives in use on the Northern Pacific Railway is 10.4 years. There are in service (or, at least, there were two years ago) several locomotives 34 years old. This road has been in existence so long that its rolling stock may be said to have reached a condition of normal renewals. When a condition of normal renewals is reached as to cross ties, the life of the average tie is just twice the age of the existing average tie. If the age of the average tie is found to be 5 years, and a condition of normal renewals of 10 per cent per annum exists. In like manner, rolling stock ultimately approximates a condition of normal renewals. It does not reach exactly that condition, due to the steady growth of traffic on the railway. But, if we multiply the 10.4 years by 2, we have 20.8 years, which is the approximate average life of locomotives on the Northern Pacific Ry. Due to the increase in the number of locomotives each year, the true average life is slightly greater than the 20.8 years thus ascertained.

Since there has been a complete renewal of locomotives in about 20 years, and since the locomotives have grown progressively heavier, it is logical to look for a renewal of steel bridges in about the same length of time and in fact that is what has occurred. Table I shows the life of 10 bridges.

TABLE I.—SHOWING LIFE OF TEN RAILWAY BRIDGES.

Item No.	Name of R. R.	Location of Bridge.	When Built.	Life, Years.
1	C., M. & St. P.	Rock River	1884	19
2	Wabash	Sangamon River	1885	21
3	C., B. & Q.	Big Rock Creek	1881	22
4	Ill. Cent.	Big Muddy River	1889	13
5	Ill. Cent.	Tennessee River	1888	17
6	C. & N. W.	Kinnikinnic River	1880	19
7	P. M.	St. Joseph River	1887	17
8	Grand Trunk	Niagara	1877	19
9	C., M. & St. P.	Menominee River	1886	17
10	C. R. R. of N. J.	Newark Bay	1887	17
	Average of the above			18.1

It will be noted that the average life of these 10 steel railway bridges has been 18.1 years. When it is remembered that the life of an uncovered Howe truss wooden bridge is rarely less than 10 years and is frequently 20 years (see committee report of the Association of Railway Superintendents of Bridges and Buildings, October, 1899), what becomes of the designation "permanent" as applied to steel in contrast with wooden railway bridges? The consensus of opinion given in the report above cited was to the effect that a Howe truss, properly housed in, would last more than 40 years. A housed in wooden highway bridge, of the Howe truss type, was taken down at Zanesville, Ohio, after 65 years of service.

With such statistics before us, we are forced to conclude that most railway bridge engineers have fallen into serious error in not giving proper consideration to the temporary character of steel railway bridges as heretofore designed.

While we cannot predict with accuracy what the increase in railway bridge loading will be in the future, there is nothing more certain than that an increase will occur. Since the first railway was built, there has been a steady growth in the size of locomotives and cars. When will it cease? No man can tell. Therefore, if we plan for the future upon the teachings of the past 80 years, we must either make due allowance for increased weight of rolling stock when designing steel railway bridges, or we must cease calling them "permanent" and apply to them, as to timber bridges, their proper designation, "temporary."

In addition to the important bearing that such statistics as are here given have upon bridge design, there is the further importance of such data in solving problems of railway appraisal. In making his appraisal of railways of Washington for the State Railroad Commission, Mr. H. P. Gillette had to make an estimate of the "present value" of all structures. Nearly all the steel railway bridges in Washington are comparatively new, and, as the appraisal of the railways was made primarily for rate making purposes, Mr. Gillette assigned no depreciation to the steel bridges. This gave the railways more than "the benefit of the doubt," for there can be no doubt that there is no real permanency in steel railway bridges as at present designed. For taxation purposes, it is clear that a depreciation of about 5 per cent per annum should be made from the first cost of all steel railway bridges.

Even a casual study of bridge books and bridge literature must impress an engineer with the lack of attention that engineers have given to this all important subject of the life of bridges. The text books treat the problems of bridge design largely as problems in pure mathematics and mechanics, and ignore many equally important principles of bridge economics. Most of the designers of reinforced concrete railway bridges are making the same blunders that have characterized the designers of steel railway bridges, namely, designing for present loadings without provision for the future.

Life of Railway Bridges.—Mr. J. E. Greiner states that the life of iron or steel railway bridges "has been scarcely 25 years," due to the steady increase in the weight of locomotives. He gives the following table of weights of locomotives in the Baltimore & Ohio Ry., for 60 years:

Year.	Weight in tons.
1835	10.7
1851	37.3
1863	45.4
1873	52.6
1881	54.3
1886	56.6
1890	66.5
1894	80.4
1895	95.0 (electric)

The increase between 1885 and 1895 has been 75%, or 7½% per annum. The increase between 1835 and 1895 has been 788% for 60 years, or 13% per annum.

Amount of Work Done Per Man in a Large Bridge Works.—At the Pencoyd works of the American Bridge Co. the following was the amount of work done in the first half of the year 1901: The number of men employed was 765 (of whom 98 were draftsmen) and the output was 82,600,000 lbs. in 6 mos., or nearly 13,800,000 lbs. per mo. The average output per man per month was, therefore, 18,300 lbs. The output of each of the different classes of men was as follows per month:

	Pounds.
Draftsmen (98 men)	140,000
Templaters (30 men)	455,000
Bridge shop	21,300
Forge	11,000
Eye-bar shop	35,400

The output per draftsman was found by dividing the total output of the works by the number of draftsmen employed; in like manner the output per templater was calculated; but the output of each man in the bridge shop, forge and eye-bar shop was calculated only on the basis of the number of pounds handled in each of those departments.

Cost of Erecting A., T. & S. F. Ry. Bridges.—The average cost per ton of the bridges erected on the Atchison, Topeka & Santa Fe Ry., in 1907, all of which were on the main line of this railway, and consequently made it necessary to contend with all trains was as follows:

	Per ton.
Trusses, 984 tons erected	$4.63
Girders, 2,784 tons erected	5.49
I-beams, 2,837 tons erected	2.88

All the girders and I-beams were erected with steam wrecker and through spans with the derrick car. It will be noticed that the girder work cost more than the trusses, the reason for this being that a good part of the girder work was on second track, where one girder had to be cut apart and moved to the outside and a heavier girder set in its place. The bridge gang traveled over a territory of 5,000 miles and the cost of moving was also charged to the bridges. The riveting was done by hand.

Falsework for a Railway Bridge.*—The new Havre de Grace bridge for the Pennsylvania R. R. in Maryland of 255 ft. and one of 192 ft., is a double track deck truss structure about 4,115 ft. long composed of one 280-ft. swing span and 17 fixed spans from 192 ft. to 255 ft. long. The swing span and the 8 fixed spans were fabricated and erected by the American Bridge Co. The swing span was erected up and down stream on the fender, and the fixed spans were erected on pile trestle falsework. The construction of the falsework trestle, the method of its erection, and the total and unit quantities of lumber used are given in this article from data furnished by Mr. H. F. Lofland, General Manager of Erection, American Bridge Co., Philadelphia, Pa.

---

*Abstracted from *Engineering-Contracting*, June 5, 1907, but omitting the drawings.

Under the shore span (192 ft.) a falsework of framed bents constructed was employed. In deeper water pile bents were used with the caps directly on the pile tops and every other panel braced. The number of piles in a bent was increased with the increase in the depth of water; for spans 2, 3, 8 and 9 six pile bents were used, and for spans 4 and 7 eight pile bents, while spans 5 and 6 had double bents of eight piles each. The 8-pile double bents were two bents of 8 piles each, the bents being spaced 4 ft. c. to c. The longitudinal bracing was universally 4x8-in. stuff for diagonals and 6x8 in. stuff for horizontals.

The method of construction was to drive the piles for all nine spans complete, then to complete the falseworks for the first five spans and finally to transfer the caps and bracing to spans 6, 7, 8 and 9 from preceding spans as fast as these were erected. The piles ran from 50 to 90 ft. in length and were driven to a penetration of 25 ft. in all spans except 5 and 6, where a penetration of only 20 ft. was permitted. The schedule of piles for the several spans was as follows:

Spans.	No. piles.	Total lin. ft.
2-3	48	2,400
3-4	48	2,550
4-5	64	4,320
5-6	128	9,920
6-7	128	11,200
7-8	64	4,400
8-9	48	2,760
9-10	48	2,880
Total	576	40,430

There were, therefore, about 18 lin. ft. of piling used for lineal foot of span, not counting the posts in the pier bents.

The falseworks were proportioned for a maximum concentrated live load at one corner of the traveler of 35,000 lbs.; it was also proportioned for the following panel loads; 192-ft. span, dead load due to steel superstructure, 45,000 lbs., live load due to hauling out materials, 24,000 lbs.; 255-ft. spans, dead load, 79,000 lbs., live load, 35,000 lbs. As stated above, caps and bracing for spans 2, 3, 4 and 5 were reared in spans 6, 7, 8 and 9. The total falsework in addition to piling was then:

Span. Description.	Ft. B. M.
1-2—Bents and bracing	22,720
2-3—Caps and bracing	12,147
3-4—Caps and bracing	12,147
4-5—Caps and bracing	20,325
5-6—Caps and bracing	31,824
Total	99,163

This total is exclusive of the timber in the posts of the pier bents. These posts are 12x12 ins., and average about 41 ft. in length; there are four posts to each bent and 17 bents. They contain, therefore, $492 \times 4 \times 17 = 33{,}456$ ft. B. M., which, added to the above total, gives 132,619 ft. B. M., or 60 ft. B. M. per lineal foot of bridge (river spans). The total weight of steel in the river

spans was 16,000 tons, so that there were used 6.74 lin. ft. of piling and about 22.1 ft. B. M. of falsework timber per ton of steel.

Cost of a Steel Railway Bridge and Foundations.—Mr. W. A. Rogers gives the following data relative to erecting a 4-span single track bridge across Grand River, Mo., for the C., M. & St. P. Ry. in 1895. The 4 spans were 138 ft. long each, and weighed 178,600 lbs. each. The work was done by company forces at the following cost:

Falsework—	
Materials	$1,606.90
Labor	1,834.99
Train service	150.00
Total	$3,591.89
Two Pile Piers—	
Material	$ 420.24
Labor	287.00
Train service	40.00
Total	$ 747.24
Foundation Three Masonry Piers—	
Material (piles and timber grillage)	$ 601.40
Labor	1,773.00
Total	$2,374.40
Stonework Three Masonry Piers—	
343,080 lbs. stone	$2,061.93
501 sacks cement	176.90
Miscellaneous material	22.94
Labor	3,485.53
Total	$5,747.30
Iron Superstructure—	
700,009 lbs. wrought iron	$17,216.91
14,489 lbs. cast iron	195.43
Miscellaneous	21.06
Labor erecting	1,952.97
Train service	96.78
Total	$19,483.15
Floor—	
Materials	$1,051.32
Labor	292.82
Total	$ 1,344.14
Moving the Spans—	
Materials	$ 136.62
Labor	521.99
Train service	58.20
Total	$ 716.81
Removing old pile piers, pulling piles, and removing falsework	593.05
Removing driftwood (burning)	938.78
Night watchman	465.50
Engineering	1,145.96
Grand total	$37,148.22

This is equivalent to nearly $70 per lin. ft. for the 552 lin. ft.

The first item of falsework includes taking down 4 old Howe truss bridges. The falsework item amounts to $6.53 per lin. ft., and is equivalent to 0.5 cts. per lb. of iron in the bridge. The erection of the iron cost 0.29 ct. per lb., which added to the 0.5 ct. makes a total of about 0.8 ct. per lb. for erection and falsework, or $16 per ton.

The stone masonry required 4,800 lbs. of stone in the rough per cu. yd., and cost $8.04 per cu. yd., of which $4.87 was labor.

The floor, or deck, cost $22.22 per 1,000 ft. B. M., or $2.44 per lin. ft. for labor and materials, of which $0.52 per lin. ft. was for labor.

The four spans were erected on the old piers and subsequently moved 30 ft. lengthwise on rollers riding on temporary plate girder spans; the cost of this moving was $179 per span, or 0.1 ct. per lb. It took 6½ days to move the spans, although it took only 15 mins. to pull a span from the old pier to the new, using a locomotive.

Engineering was 3% of the total cost.

Cost of a Steel Bridge of 155-ft. Span.—The following data appeared in *Engineering-Contracting*, Apr. 3, 1907, and relate to the cost of building a steel railway bridge of 155 ft. span (total weight 131 tons), to take the place of an old Howe truss bridge. Two concrete abutments on pile foundations were built at a cost of $2,600 each, or $5,200 for both abutments. There was nothing unusual about this abutment work, so its cost will not be given in detail. All work was done by "company forces," and the itemized cost is given below.

Wages were $3.40 per 10-hour day for foreman, $2.50 for bridgemen, and $2.00 for laborers. The engineman on the hoisting engine received $2.50 a day, and the fireman received $2.00. In traveling to and from the site of the work, the time of the men amounted to 16 days.

Time traveling, 16 days, at $2.50		$ 40.00
Erecting Traveler—		
3 days at $3.40	$ 10.20	
30 days at $2.50	75.00	
9 days at $2	18.00	
		$ 103.20
Rigging Blocks and Tackle on Traveler—		
½ day at $3.40	$ 1.70	
6 days at $2.50	15.00	
1½ days at $2	3.00	
		$ 19.70
Loading Engine on Derrick Car for Erection—		
½ day at $3.40	$ 1.70	
6 days at $2.50	15.00	
1½ days at $2	3.00	
		$ 19.70
Taking Traveler Down—		
1 day at $3.40	$ 3.40	
6 days at $2.50	15.00	
2 days at $2	4.00	
		$ 22.40

Picking Up Tools After Erection—		
4 days at $2.50		$ 10.00
Unloading Bridge Steel—		
2⅓ days at $3.40	$ 8.70	
19 days at $2.50	47.50	
6 days at $2	12.00	
		$ 68.20
Painting Inaccessible Parts with Two Coats—		
8 days at $2.50	$ 20.00	
14 days at $2	28.00	
		$ 48.00
Erecting Bridge Trusses—		
6 days at $3.40	$ 20.40	
96 days at $2.50	240.00	
6 days (enginemen) at $2.50	15.00	
6 days (firemen) at $2	12.00	
		$ 287.40
Removing Old Deck and Pony Bents to Erect Floor System—		
1 day at $3.40	$ 3.40	
9 days at $2.50	22.50	
		$ 25.90
Putting in Steel Floor System—		
2 days at $3.40	$ 6.80	
32 days at $2.50	81.25	
2 days at $2	4.00	
2½ days (enginemen) at $2.50	6.25	
		$ 103.30
Getting tools, etc., ready for riveting—		
4 days at $2.50		$ 10.00
Riveting—		
40 days at $3	$120.00	
40 days at $2.50	100.00	
9 days (blacksmith) at $3	27.00	
		$ 247.00
Putting in Machine Fit Bolts—		
2 days at $3.40	$ 6.80	
8 days at $2.50	20.00	
		$ 26.80
Timber Deck—Handling Ties—		
½ day at $3.40	$ 1.70	
3 days at $2.50	7.50	
1 day at $2	2.00	
		$ 11.20
Framing Ties—		
1 day at $3.40	$ 3.40	
5 days at $2.50	12.50	
4 days at $2	8.00	
		$ 23.90
Placing and Fitting Ties—		
1 day at $3.40	$ 3.40	
7 days at $2.50	17.50	
		$ 20.90
Framing and Fitting Guard Rail—		
1 day at $3.40	$ 3.40	
4 days at $2.50	10.00	
2 days at $2	4.00	
		$ 17.40
Boring and Bolting Guard Rail and Ties—		
8 days at $2.50		$ 20.00
Total labor on superstructure		$1,125.00

This is equivalent to practically $7.80 per lineal foot of bridge, or $8.59 per ton. The labor cost per ton of bridge may be summarized as follows:

	Per ton.
General labor, $215	$1.64
Unloading steel, $68.20	.52
Painting inaccessible parts, $48	.37
Removing old deck, $25.90	.20
Erecting trusses and floor system, $390.70	2.98
Riveting and machine bolts, $283.80	2.17
Timber deck work, $93.40	.71
Total	$8.59

Strictly speaking, the items of labor on the timber deck should not be charged as a part of the cost of work on the steel portion of the bridge. The labor on the ties and guard rails, it will be seen, amounted to 60 cts. per lineal foot of bridge. It will be noted that there is no charge for fuel used by the hoisting engine, nor for transportation charges on the engine and materials for the traveler. The hoisting engine was in use 9 days, so that the fuel item could not have exceeded $30, and was doubtless much less.

The following is a summary of the total cost of this steel bridge on its concrete abutments:

Two concrete abutments	$ 5,200.00
Removing old bridge	200.00
Falsework	1,220.00
Bunk house	40.00
Materials in superstructure	7,200.00
Labor erecting superstructure	1,125.00
Engineering and inspection	585.00
Total	$15,570.00

This is practically $100 per lineal foot of bridge, including cost of abutments.

It will be noted that the false work cost about $8 per lineal foot of bridge, and amounted to a little more than the labor cost of erecting the bridge; but this cost of $1,220 for false work included both labor and materials. The cost of false work for ordinary bridges like this can be estimated as equivalent to the cost of a pile trestle, unless the height of the lower chord of the bridge above the bed of the river is so great as to necessitate building one or more decks of framed bents on top of the pile bents.

Cost of a Steel Bridge of 180-ft. Span.*—In our last issue we gave details of the cost of erecting a railway bridge of 155 ft. span. The general remarks relating to that bridge also apply to the one discussed in this article. Both bridges were through spans, riveted trusses, on concrete piers, erected by company forces. This 180-ft. bridge had a total weight of 172 tons. The cost of erecting the bridge was as follows:

Building Traveler—

1½ days, foreman, at $3.40	$ 5.10	
11 days, carpenters, at $2.50	27.50	
		$ 32.60

*Engineering-Contracting, Apr. 10, 1907.

Erecting Traveler—

1½ days, foreman, at $3.40	$ 5.10	
12 days, carpenters, at $2.50	30.00	
10 days, laborers, at $2.25	22.50	
½ day, work train at $25	12.50	
		$ 70.10

Rigging Traveler with Blocks, Tackle, etc.—

1½ days at $3.40	$ 5.10	
10 days at $2.50	25.00	
10 days at $2.25	22.50	
		$ 52.60

Taking Down Traveler—

½ day at $3.40	$ 1.70	
5 days at $2.50	12.50	
5 days at $2.25	11.25	
1 day, stationary engineer, at $3	3.00	
		$ 28.45

Gathering Up Tools, Engine, etc., After Erecting—

1 day at $3.40	$ 3.40	
5 days at $2.50	12.50	
3 days at $2.25	6.75	
1 day, work train, at $25	25.00	
		$ 47.65

Raising Derrick for Unloading Bridge Materials—

½ day at $3.40	$ 1.70	
2½ days at $2.50	6.25	
3 days at $2.25	6.75	
1 hour, stationary engineer, at 30c	.30	
1 hour, work train, at $2.50	2.50	
		$ 17.50

Building Platform for Bridge Materials—

1 day at $3.40	$ 3.40	
8 days at $2.50	20.00	
10 days, laborers, at $2.25	22.50	
		$ 45.90

Unloading Bridge Steel—

2½ days at $3.40	$ 8.50	
7 days at $2.50	17.50	
14 days at $2.25	31.50	
2½ days, stationary engineer, at $3	7.50	
1 day, work train	25.00	
		$ 89.00

Painting Inaccessible Parts, Two Coats—

6 days at $3.40	$ 20.40	
4 days at $2.50	10.00	
21 days at $2.25	47.25	
		$ 77.65

Unloading and Placing Stationary Engine for Erecting Bridge—

½ day at $3.40	$ 1.70	
4 days at $2.50	10.00	
4 days at $2.25	9.00	
1 day, stationary engineer	3.00	
		$ 23.70

Erecting Steel Trusses—

5 days at $3.40	$17.20	
40 days at $2.50	100.00	
40 days at $2.25	90.00	
5 days, stationary engineer, at $3.00	15.00	
1 day, work train	25.00	
		$ 247.20

Taking Out Pony Bents to Erect Floor System—		
2½ days at $2.50	$ 6.25	
2 days at $2.25	4.50	
		$ 10.75
Putting in Steel Floor System—		
5 days at $3.40	$ 17.20	
30 days at $2.50	75.00	
26 days at $2.25	58.50	
4 days, stationary engineer, at $3	12.00	
		$ 162.70
Riveting—		
50 days at $3	$150.00	
60 days at $2.50	150.00	
32 days at $2.25	71.00	
15 days, blacksmith, at $2.50	37.50	
		$ 408.50
Putting in Machine Fit Bolts—		
1 day at $3	$ 3.00	
4 days at $2.50	10.00	
9 days at $2.25	20.25	
		$ 33.25
Timber Deck—Framing Ties—		
1½ days at $3.40	$ 5.10	
8 days at $2.50	20.00	
4 days at $2.25	9.00	
		$ 34.10
Placing and Fitting Ties—		
1 day at $3.40	$ 3.40	
2½ days at $2.50	6.25	
9 days at $2.25	20.25	
		$ 29.90
Framing and Fitting Guard Rail—		
1 day at $3.40	$ 3.40	
4 days at $2.50	10.00	
4 days at $2.25	9.00	
		$ 22.40
Boring and Bolting Guard Rail and Ties—		
7 days at $2.50	$ 17.50	
1 day at $2.25	2.25	
		$ 19.75
Taking Out Old Deck—		
½ day at $3.40	$ 1.70	
1 day at $2.50	2.50	
1½ days at $2.25	3.35	$ 7.55
Total labor		$1,461.25

This is equivalent to $8.10 per lin. ft. of bridge, or $8.48 per ton.

It will be seen that it took 50 days of labor, including foreman, but excluding work train crew, to erect the bridge, thus making the average wage about $2.60 per day of 10 hours.

In comparing labor costs per unit of work done, it is always well to state the average wage paid, for, otherwise, serious errors may be made in comparing unit costs given only in dollars and cents. Wages have been rising so rapidly within recent years that the necessity of stating the average wage is more urgent than ever.

The wages of the foreman constituted 7 per cent of the total wages paid.

The cost per ton for erecting this bridge may be summarized as follows:

	Per ton.
Preparing and dismantling plant, $318.50	$1.85
Unloading steel, $89	.52
Painting inaccessible parts, $77.65	.45
Erecting trusses and floor system, $420.65	2.45
Riveting and machine bolting, $441.75	2.55
Timber deck work, $113.70	.66
Total	$8.48

It will be seen that the work on the timber deck cost 63 cents per lin. ft. of bridge.

The total cost of this bridge on concrete abutments with pile foundations was as follows:

Two concrete abutments, materials and labor	$ 4,700
Materials for superstructure	9,500
Labor erecting superstructure	1,461
Falsework and removal of old bridge	2,800
Engineering and superintendence	370
Total	$18,831

This is practically $105 per lineal foot of bridge, including abutments.

Cost of Two Steel Truss Bridges of 180-ft. Span, and One Plate Lattice Girder Bridge of 100-ft. Span.*—In our issue of April 10, we gave the detailed cost of erecting a steel bridge of 180 ft. span. The following data relate to two spans, also of 180 ft. each, on which the labor of erection cost was very much less per ton than the cost given in our issue of April 10. This difference appears to have been due to better management and more efficient workmen on the work about to be described. These two 180-ft. spans were erected by a contractor, and the costs are the actual costs to the contractor, exclusive of contractor's profits. The bridges were single track, through, riveted trusses erected with a traveler. The average force engaged was as follows:

1	General foreman at	$5.00	$ 5.00
1	Carpenter foreman at	4.00	4.00
1	Sub-foreman at	3.50	3.50
7	Riveters, etc., at	3.25	22.75
10	Bridgemen at	3.00	30.00
8	Carpenters at	2.75	22.00
3	Laborers at	2.50	7.50
1	Stationary engineman at	3.25	3.25
1	Water boy at	1.50	1.50
33	Total men	$3.00	$99.50

It will be noted that the average wage paid was $3 per day of 10 hours, as compared with $2.60 on the bridge described in our issue of April 10. No attempt was made to record the exact cost of each item of the work, but account was kept of the number of

*_Engineering-Contracting_, May 8, 1907.

men and the number of days required to perform each item of the work, and the average wage was assumed to be $3 per man day.

Preparatory Work—	
50 Man days traveling at $3	$ 150.00
50 Man days erecting traveler and derricks at $3	150.00
12 Man days taking down same	36.00
40 Man days removing old floor at $3	120.00
20 Man days unloading steel and ties	60.00
Steel Work—	
70 Man days putting in new steel floor system at $3	210.00
100 Man days erecting steel trusses at $3	300.00
125 Man days riveting	375.00
Timber Deck—	
20 Man days framing ties at $3	$ 60.00
30 Man days laying floor at $3	90.00
Painting—	
46 Man days, first coat	138.00
42 Man days, second coat	126.00
Total labor	$1,815.00
Wear of tools, ropes, etc	100.00
Coal for engine and blacksmith	70.00
Total	$1,985.00

The steel in each of the two bridges weighed 170 tons, or 340 tons in both bridges, or 1,800 lbs. per lin ft. Summarizing the cost of erection, we have:

	Per ton.
Lost time traveling, $150	$0.44
Erecting and taking down plant, $186	0.56
Removing old floor system, $120	0.35
Unloading steel and ties, $60	0.18
Steel work, $885	2.60
Timber deck work, $1.50	0.44
Painting, $264	0.78
Wear of tools, $100	0.30
Coal, $70	0.20
Total	$5.84

The above does not include the cost of erecting the falsework, but it includes the item of "removing old floor system" or the wooden bridge which was replaced by the new steel bridge.

It will be noted that the labor on the timber deck of the new bridge cost only $150, which is equivalent to 40 cts. per lin. ft. This is about two-thirds the cost of similar work given in our issue of April 10. In fact the whole cost of erection was correspondingly less in this bridge work, in spite of the fact that the daily wages averaged 15 per cent higher. A comparative study of this sort will frequently disclose unsuspected inefficiency of men and foremen.

We shall next consider the cost of erecting a steel plate lattice girder of 100 ft. span. This girder was erected by company forces, and it replaced a wooden bridge. The weight of the steel was 82 ns, or 1,640 lbs. per lin. ft. It was erected by a force of 18 men 0 days, including 2 days spent in traveling, and the average

wage paid was $3.18 per day, including the foremen in the average. The foremen's wages amounted to 13 per cent of the total wages paid, which was an unusually high percentage. The rate of wages were as follows:

General foreman	$ 5.00
Sub-foreman	3.50
Drivers of rivets	3.25
Heaters of rivets	3[illegible]
Buckerup of rivets	[illegible]
Bridgemen	3.00
Carpenters	2.75
Stationary engineman	3.25

Time Traveling—

2 days at	$5.00	$ 10.00
2 days at	3.50	7.00
12 days at	3.25	39.00
18 days at	3.00	54.00
4 days at	2.75	11.00
38 days total at	$3.18	$121.00

Rigging—

1 day at	$5.00	$ 5.00
1 day at	3.50	3.50
4 days at	3.50	13.00
6 days at	3.00	18.00
12 days total at	$3.30	$ 39.50

Loading Tools—

2 days at	$5.00	$ 10.00
2 days at	3.50	7.00
5 days at	3.25	16.25
5 days at	3.00	15.00
14 days total at	$3.45	$ 48.25

Steel Work—Erecting Girders—

1 day at	$5.00	$ 5.00
1 day at	3.50	3.50
4 days at	3.25	13.00
6 days at	3.00	18.00
12 days at	$3.30	$ 39.00

Erecting Floor System—

1 day at	$5.00	$ 5.00
1 day at	3.50	3.50
10 days at	3.25	32.50
12 days at	3.00	36.00
24 days total at	$3.21	$ 77.00

Riveting—

2 days at	$5.00	$ 10.00
2 days at	3.50	7.00
18 days at	3.25	58.50
20 days at	3.00	60.00
42 days total at	$3.23	$135.50

Timber Deck—

6 days framing ties at	$2.75	$ 16.50
12 days laying floor at	2.75	33.00
18 days total at	$2.75	$ 49.50

Painting—

10 days at	$3.25	$ 32.50
10 days at	3.00	30.00
20 days total at	$3.12	$ 62.50

Total labor	$572.75
Wear of tools	35.00
Coal	10.25
Total	$618.00

Summary—

		Per ton.
Traveling	$121.00	$1.48
Rigging	39.50	0.48
Loading tools	48.25	0.59
Steel work	252.00	3.08
Timber deck	49.50	0.60
Painting	62.50	0.76
Tools and coal	45.25	0.55
Total	$618.00	$7.54

It will be noted that the cost of work on the timber deck was 49½ cts. per lin. ft.

The cost of building the false work is not included in the above estimate.

Cost of Erecting a Draw Bridge of 236-ft. Span.*—This single track railway bridge has a span of 236 ft., and a length of 239 ft. over all. Trusses are 16 ft. c. to c., and the depth of truss is uniform and 25 ft. c. to c. of chord pins. The center panel is 16 ft. and the remaining 10 panels are each 22 ft. The bridge is designed to be turned by hand only, and has a drum 22½ ft. x 4¾ ft. The bridge was designed for a live load of 3,300 lbs. per lin. ft.

The total weight of the metal is 433,300 lbs., distributed as follows:

	Lbs.
Trusses	205,60
Lateral bracing	20,000
Floor system	107,000
Turntable—	
Drum (22½ ft. diam.)	21,400
Wheels (46)	16,200
Track	11,100
Rack	4,900
Tread pls.	5,200
Gearing and journal boxes	25,400
End lift	10,200
End supports	6,300
Total	433,300

**Engineering-Contracting*, Aug. 21, 1907.

The itemized cost (to the contractor) of erection was as follows:

General Expense:

7.5 days, foreman at $5.00	$ 37.50
44 days, bridgemen, at $3.00	132.00
34 days, laborers, at $2.00	68.00
10 days, watchman, at $2.00	20.00
3 days, blacksmith, at $3.00	9.00
98.5 Total labor, at $2.67	$266.50
3,000 ft. B. M. in traveler, at $25	75.00
Total	$341.50

Thus $341 includes the cost of erecting a derrick to unload the steel from cars, the labor of making and erecting traveler.

Erection of Steel Work:

19 days, foreman, at $5.00	$ 95.00
110 days, bridgemen, at $3.00	330.00
80 days, riveters, at $3.00	240.00
73 days, heaters and buckers, at $2.00	146.00
84 days, laborers, at $2.00	168.00
366 Total labor, at $2.65	$ 969.00
30 days' rent of hoisting engine, at $3.00	90.00
10 tons coal, at $3.00	30.00
Total	$1,089.00

The engineman received the same wages as the bridgemen and was classed with them.

3 days, foreman, at $5.00	$ 15.00
9 days, bridgemen, at $3.00	27.00
80 days, painters, at $2.50	200.00
92 days total labor	$242.00
Total materials and labor	$337.00

Timber Deck (17,000 ft. B. M.):

3 days, foreman, at $5.00	$15.00
26 days, carpenters, at $2.75	71.50
3 days, laborers, at $2.00	6.00
32 days total labor, at $2.90	$92.50

It will be noted that the labor of framing and placing the timber deck (i. e., the ties, guard rails, etc.), cost $5.50 per M., or 38 cts. per lin. ft. of bridge.

Since the bridge weighed 433,000 lbs., or 216.5 tons, the cost per ton for erection may be summarized as follows:

		Per ton.
General Expense:		
Labor	$ 266.50	$1.23
Material for traveler	75.00	0.35
Erecting Steel:		
Labor	$ 969.00	$4.49
Rent of engine	90.00	0.42
Coal for engine	30.00	0.14

Painting:

Materials	$ 95.00	$0.44
Labor	242.00	1.11
Timber deck	92.50	0.42
Total	$1,860.00	$8.60

This work was done by a contractor who received $12 per ton for erecting the bridge. Practically no falsework was necessary, since the bridge was erected upon the "draw protection," which served as a falsework.

The bridge metal cost 4 cts. per lb. f. o. b. cars, ready for erection, and, since the contract price was 0.6 cts. for erection, the total was 4.6 cts. per lb. in place, or $19,931 for the total superstructure, exclusive of the timber deck. This is equivalent to nearly $85 per lin. ft. There were nearly 70 ft. B. M. per lin. ft. of timber deck (ties and guard rail), which cost $20 per M., or $1.40 per lin. ft. of bridge.

Cost of Erecting Pratt Truss Bridges.—A Pratt truss steel railway bridge, 130 ft. long, 14 ft. wide and 20 ft. high, was built to replace two Howe pony truss bridges, each 65 ft. long. The cost of this work was as follows:

Falsework, materials and labor	$174.00
Removing falsework	100.00
Taking down two Howe truss bridges	145.00

Wages of common laborers were $1.50, and of bridgemen $2.50 a day.

It took a gang of 20 men 45 hrs. to erect a 200-ft. span Pratt truss highway bridge, of the combination type (wooden upper chord and posts and steel lower chord and diagonals), after the pile falsework was in place. The roadway was 16 ft. wide. A hoisting engine was used, and the posts were up-ended in pairs just as trestle bents are raised. A mast was used in raising the upper chord pieces. There was no oupper falsework, nor was a traveler used.

Cost of Three-Plate Girder Bridges of Ten Spans.*—The data in this article relate to three plate girder (deck) bridges, on concrete abutments and piers, having pile foundations, built to replace existing timber bridges.

The first bridge consisted of three spans, one 30-ft. and two 75-ft. girder spans, having a total weight of 110 tons. The work was done by company forces, the details of cost being as follows:

Moving rigging from the last bridge—

½ day, foreman, at $3.40	$ 1.70
2½ days, carpenters, at $2.50	6.25
2 days, laborers, at $2.25	4.50
1 day, stationary engineer, at $3	3.00
	$15.45

Erecting portals for lowering the two 76-ft. girder spans—

1¼ days at $3.40	$ 5.10
6 days at $2.50	15.00
3 days at $2.25	6.75
	$26.85

Engineering-Contracting, April 17, 1907.

Erecting portals for lowering the 30-ft. span—

1 hour at 34 cents	$ .34
3 hours at 25 cents	.75
4 hours at $2.25	.90
1 hour, sta. engr., at 30 cents	.30
	$ 2.29

Rigging portals with blocks and tackle—

½ day at $3.40	$ 1.70
2½ days at $2.50	6.25
2½ days at $2.25	5.62
½ day, sta. engr., at $3	1.50
	$15.07

Placing two stationary engines for erecting girders—

3 hours at 34 cents	$ 1.02
1½ days at $2.50	3.75
1½ days at $2.25	3.38
½ day, sta. engr., at $3	1.50
	$ 9.65

Picking up rigging after erecting—

2 hours at 34 cents	$ .68
1 day at $2.50	2.50
1 day at $2.25	2.25
2 hours, sta. engr., at 30 cents	.60
	$ 6.03

STEEL WORK.

Putting down bearing shoes—

2 hours at 34 cents	$ .68
1 day at $2.50	2.50
1 day at $2.25	2.25
	$ 5.43

Placing and lowering the two 75-ft. spans—

1 day at $3.40	$ 3.40
5½ days at $2.50	13.75
5½ days at $2.25	12.37
1 day, engr., at $3	3.00
2 days, work train, at $25	50.00
	$82.52

Taking out pony bents to erect floor system—

1 day at $3.40	$ 3.40
6 days at $2.50	15.00
5 days at $2.25	11.25
1 day, engr., at $3	3.00
	$32.65

Painting inaccessible parts with two coats—

19 days at $2.25	$42.75

Putting in steel floor system—

2.2 days at $3.40	$ 7.48
11 days at $2.50	27.50
13 days at $2.25	29.25
3 days, engr., at $3	9.00
2 days, work train, at $25	50.00
	$123.23

Riveting—

38 days, riveters, at $3	$114.00
60 days, at $2.50	150.00
4 days, blacksmith, at $2.50	10.00
	$274.00

Putting in machine fit bolts—

7 days at $2.25	$15.75

Placing and lowering 30-ft. span—

0.3 day at $3.40	$ 1.02
1½ day at $2.50	3.75
1½ day at $2.25	3.38
0.3 day, engr., at $3	.90
½ day, train, at $25	12.50
	$21.55

TIMBER DECK.

Framing ties—

8 days at $2.50	$20.00

Placing and fitting ties—

1½ days at $3.40	$ 5.10
8 days at $2.50	20.00
6 days at $2.25	13.50
	$38.60

Framing and fitting guard rail—

½ day, foreman, at $3.40	$ 1.70
3 days at $2.50	7.50
2½ days at $2.25	5.63
	$14.83

Boring and bolting guard rails and ties—

½ day, foreman, at $3.40	$ 1.70
4½ days at $2.50	11.25
3½ days at $2.25	7.87
	$20.82

Tearing up old deck and lowering track on new bridge—

1 day at $3.40	$ 3.40
5 days at $2.50	12.50
2 days at $2.25	4.50
	$20.40
Total labor	$787.87

This is equivalent to $7.15 per ton, or $4.35 per lin. ft. of span. The cost per ton may be summarized as follows:

	Per ton.
General labor preparatory to erection, $75.34	$ .68
Painting inaccessible parts, $42.75	.39
Placing girders, $265.38	2.41
Riveting and mach. bolts, $289.75	2.63
Timber deck work, $114.65	1.04
Total	$7.15

The timber deck work cost 64 cts. per lin. ft. of span. It will be noted that there were 4½ days of work train service costing $112.50, or $1.02 per ton. Deducting this, we have $675 left, to be divided by 247 days' labor, which gives $2.73 as the average wage paid. There

were 13 days of foreman's time, which amounted to $44, or less than 7% of the 675.

The total cost of this bridge was:

Four concrete abutments and piers	$ 7,950
Materials in superstructure	5,600
Labor erecting superstructure	788
False work	770
Engineering and inspection	500
Total	$15.608

This is practically $85 per lin. ft. of bridge, including abutments and piers. The falsework cost about $4 per lin. ft. of bridge, or practically as much as the labor of erecting the spans.

It will be seen that the substructure cost more than the superstructure.

The second bridge was three 60-ft. plate girder spans, having total weight of 69 tons, on concrete abutments and piers. The cost of erecting by company forces was as follows:

Erecting false bents for lowering girders—	
1 day, foreman, at $3.40	$ 3.40
4 days, carpenters, at $2.50	10.00
10 days, laborers, at $2.25	22.50
	$35.90
Tearing up old bridge deck and pony bents—	
0.8 day at $3.40	$ 2.72
5.6 days at $2.50	14.00
5.6 days at $2.25	12.60
	$29.32
Placing and lowering girders from flat cars to piers—	
1.2 days at $3.40	$ 4.08
8.4 days at $2.50	21.00
8.4 days at $2.25	18.90
	$43.98
Framing ties—	
1.5 days at $3.40	$ 5.10
14 days at $2.50	35.00
	$40.10
Putting ties in place and relaying track—	
0.3 day at $3.40	$ 1.02
2.1 days at $2.50	5.25
2.1 days at $2.25	4.73
	$11.00
Framing and placing guard rail—	
1.5 days at $3.40	$ 5.10
8 days at $2.50	20.00
6 days at $2.25	13 50
	$38.60
Tearing down false bents—	
0.1 day at $3.40	$ .34
0.7 day at $2.50	1.75
0.7 day at $2.25	1.57
	$3.66

Work train on erection—

3 days at $25	$75.00
Total labor	$277.56

This is equivalent to $4.02 per ton, which may be summarized as follows:

	Per ton.
Erecting and tearing down false bents, $39.56	$ .57
Tearing up old bridge deck and pony bents, $29.32	.42
Placing girders, $43.98	.64
Timber deck work, $89.70	1.30
Work train service, $75	1.09
Total	$4.02

The labor cost of $277.56 is equivalent to $1.54 per lin. ft. of span. Tearing up old bridge deck and pony bents cost 16 cts. per lin. ft. The cost of the timber deck work was 50 cts. per lin. ft.

Exclusive of the train service, the total labor cost of erection was $202, which, divided by the 82 days, is $2.46 per day. The foreman worked 6½ days, receiving $22, which is 11% of the labor cost, exclusive of train service, or 8%, including train service. As noted above, it took 1 foreman and 14 men 12 hours to place and lower the three girder spans. The first span took 5 hours; the second span, 4 hours; and the third span, 3 hours.

After erecting the new bridge, at the cost above given, it took the gang about a day additional to tear down the old wooden bridge, at a cost of $44.

The total cost of this three-span girder bridge was:

Four abutments and piers	$ 5,400
Materials in superstructure	3,600
Labor erecting superstructure	278
False work	650
Engineering and inspection	340
Total	$10,268

This is $55 per lin. ft. of bridge. The falsework cost $3.50 per lin. ft.

The third bridge consisted of two 75-ft. girder spans and two 70-ft. girder spans (through bridge) on concrete abutments having pile foundations. The rates of wages paid were the same as on the first bridge, given above, and the cost per ton and per lin. ft. of bridge were about the same. The summary of the cost is as follows, the total weight of the four-span bridge being 197 tons:

	Per ton.
Removing old deck and placing girders, $295.50	$1.50
Putting in floor system, $309.30	1.57
Riveting, $482.80	2.40
Painting inaccessible parts, $13.80	.07
Timber deck work, $112.30	.57
Train service, $275.80	1.40
Total	$7.51

The timber deck work cost 40 cts. per lin. ft. of bridge. The total labor cost of erection was $1,480, or $5 per lin. ft. of bridge.

The total cost of the bridge was as follows:

Five piers and abutments	$ 9,100
Materials in superstructure	10,700
Labor erecting superstructure	1,480
False work	1,320
Removing old bridge	520
Bunk house	60
Engineering and inspection	500
	$23,680

This is nearly $80 per lin. ft. of bridge. The falsework cost $4.40 per lin. ft.

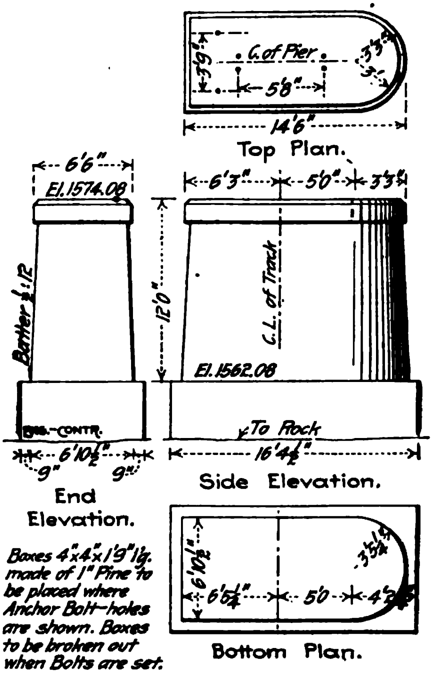


Fig. 1.—Bridge Pier.

Cost of a Plate Girder Railway Bridge with Concrete Piers.*—A deck plate girder railway bridge was constructed in the late Fall and in the Winter of 1905-6 to carry the Kansas City, Mexico & Orient Railway over the South Canadian River about 7 miles south of Oakwood, in Dewey County, Oklahoma. The whole structure was built

*Engineering-Contracting, April 3, 1907.

by company forces and the following account of the methods of work and its cost has been prepared from information furnished by Mr. W. W. Colpitts, Assistant Chief Engineer, Kansas City, Mo.

Description of Bridge.—At the point of crossing, the river at ordinary high water is from 2,000 ft. to 4,000 ft. wide and drains approximately 1,000 square miles of territory consisting largely of rolling prairie. At low water the stream is shallow and easily fordable. The extreme rise at high water is about 10 ft., and at such periods the velocity of the current exceeds 6 miles per hour. The river bottom is quicksand and varies in depth to the underlying rock at the point of crossing from 12 to 60 ft.

After a careful study of the conditions respecting the elevations of high water, depth of foundation, nature of approaches and general character of the stream, a layout consisting of 1,000 ft. of 50-ft. deck plate girders at the north end where the rock is within 12 to 18

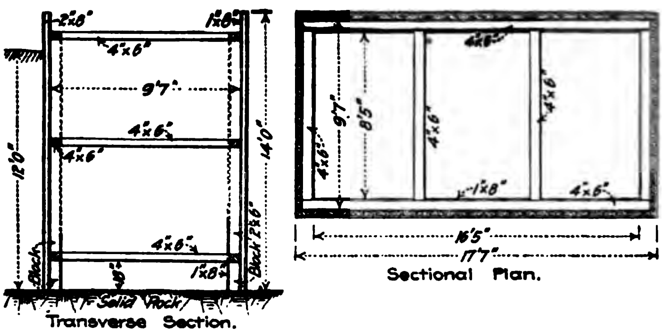


Fig. 2.—Cofferdam.

ft. of the surface, and of 1,000 ft. of pile trestle at the south end where the rock shelves off to a maximum depth of 60 ft., was decided upon as the most economical structure to fulfill the necessary requirements. The grade line was established to admit of replacing the pile trestle portion of the structure with 70 and 85 ft. deck plate girders at a later period. A concrete abutment and concrete piers were designed to carry the 50-ft. plate girders. Figure 1 shows the dimensions and details of the piers.

Methods of Construction.—The work was begun in the late fall, when an extreme rise in the river was unlikely to occur, and the very low cost of the structure was partially due to the fact that the work was little interfered with by high water. Telephone communication was established with Teloga, a point about 40 miles up the river, and a watchman stationed at that point observed and reported the stage of water at frequent intervals.

The concrete in the piers was of the following proportions: Iola Sunflower Portland cement, one part; Arkansas River sand, furnished by Messrs. Luttgerding Bros., of Wichita, Kan., three parts; crushed limestone, passing a 2-in. ring, furnished by the Frazier Stone Co., of El Dorado, Kan., five parts. The concrete in the bridge seats was of the proportions, 1-2-4.

The bases of the piers and abutment were put down in open coffer dams, Fig. 2. The sheet piling, Fig. 3, for the first pier was driven with a light hammer, but this was found to be both slow and inefficient. The lower strata of sand proved to be more compact than had been anticipated, and, by this method, considerable difficulty was experienced in driving the sheet piles accurately and in preventing leaky joints. The balance of the sheet piling was driv^^ with a 2-in. jet drawn to a 1-in. nozzle, and this method proved entirely satisfactory. The water was supplied by a 7 x 5 x 10-in. Gardner Duplex pump. The pile with the jet placed in the groove

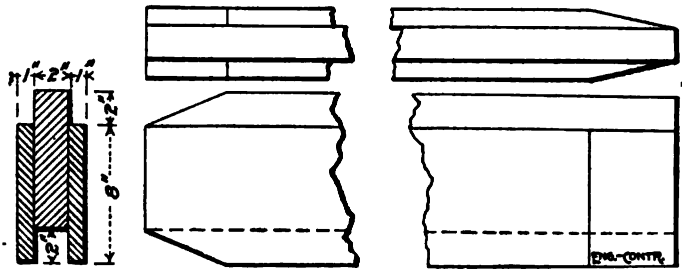


Fig. 3.—Sheet Pile.

sank rapidly and accurately with the weight of two men clinging to a hanger slung over the top of the pile. When the pile had reached the bottom, it was struck several blows with a 12-lb. sledge to broom the point on the rock.

The piles were driven between 6 x 8-in. walings, firmly secured with wrought iron clamps, to prevent irregularities in the driving. Built up angles were made for the returns at the corners and jetted to rock in the ordinary manner. The actual time required to drive a coffer dam seldom exceeded ten hours.

It was originally the intention to build a form inside the coffer dam and to gather the water from leakages in a sump at one corner to be pumped out by a pulsometer, and to withdraw the sheet piling after the completion of the base. So little difficulty was experienced in preventing leakages that this plan was abandoned and the concrete was deposited against the sheet piling, which no attempt was made to recover. It was estimated that the loss of the sheet piling was more than offset by the time and expense necessary to have built an inside form.

The sand was pumped from the coffer dam by means of a No. 4 Morris centrifugal sand pump, having a 6-inch flexible suction

pipe and protected foot valve. The power to drive this pump was furnished by a traction engine, because of the ease with which it was supported on the river bottom at the pier sites. A sufficient amount of water was allowed to flow into the coffer dam through a small weir to keep the sand of the right consistency to be handled by the pump. As the excavation proceeded, the necessary shoring was placed in position. When the sand had been completely removed, the bottom of the sheet piling was grouted with cement mortar and the coffer dam kept dry by means of the pulsometer pump, while leaks were being stopped and other necessary work done, previous to depositing concrete. Except in cases where bad leaks or accidents occurred, the time required to remove the sand from a coffer dam averaged about eight hours. It was interesting to note

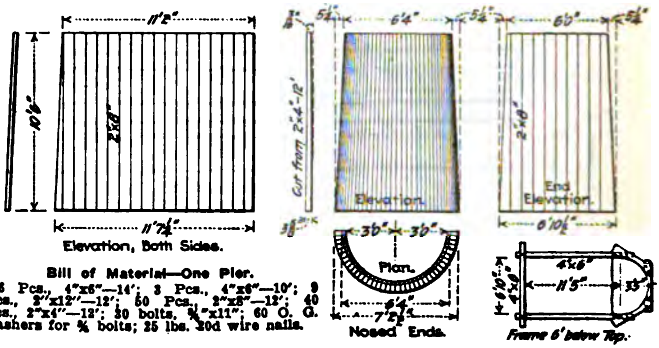


Fig. 4.—Forms for Pier.

the good state of preservation of tree trunks and limbs removed from the coffer dams. Leaves and twigs found in the compact sand near the rock were quite fresh and green.

The concrete was mixed with a No. 1 Smith mixer, having a batch capacity of about 9 cu. ft. The capacity of the machine was found to be ample to fill a coffer dam before the next ahead was completed. The mixer was placed in position on the slope of the embankment approach, with the main line track at its rear and facing a temporary material track. This temporary track turned out from the main line about 500 ft. beyond the mixer and extended diagonally down the embankment approach on a 3% grade and across the river bottom alongsside the pier sites. The portion of the track in the river bottom was supported on bents of spliced ties, jetted to the rock, and wired to the coffer dam to avoid the danger of loss in case of high water. The sand and crushed rock were delivered by cars from the main line track, immediately above the mixer, and the cement was stored in a shanty at one side of the mixer. The concrete materials and machinery were, in this man-

ner, very conveniently located for rapid work and well above the high water line. The concrete was transported to the pier sites in improvised dump boxes, set on push cars. These dump boxes were hinged longitudinally and discharged directly into the coffer dams. The grade of the temporary track carried the push cars by gravity to the coffer dams and they were returned by teams, for which purpose a straw and brush road had been built paralleling the track. As the work progressed farther into the stream, more cars were added properly to balance the work. While the concrete in the base was still fresh, a number of steel reinforcing bars, 8 ft. in length, were set in place along each end to insure a good bond between the base and shaft.

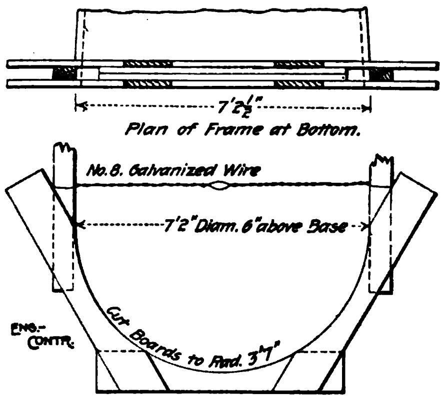


Fig. 5.

In general, the work of putting in the bases was organized so that about the same time was required in filling a coffer dam with concrete, in excavating the sand from the next, and in driving the sheet piling for the third. These three operations were thus carried on simultaneously and, although interruptions in one part of the work or the other occurred frequently, the gangs were interchangeable and no appreciable loss was suffered, except in time, because of such delays.

In piers 19 and 20, where the rock was from 17 to 19 ft. below the surface, some difficulty was encountered due to the presence of fissures in the rock, from which it was necessary to remove the sand to fill with concrete. In such cases, the larger leaks were stopped as much as possible by driving sheet piles against the outside face of the coffer dam and into the fissures, and the smaller leaks by manure in canvass bags rammed into the openings.

Upon the completion of all bases, the frames (Figs. 4 and 5) for several shafts were set in position and the work of filling with concrete proceeded as in the case of the bases, except that a derrick

erected on a flat car and stationed at the pier was utilized to raise the dump boxes in depositing the concrete in the forms. As soon as the concrete in one shaft had set sufficiently to permit of it, the forms were removed and placed on the pier ahead. Four sets of forms were used for the shafts.

The girders, which were furnished by the American Bridge Co., were set in place with a derrick car of 20 tons' capacity.

Cost of Construction.—The following are the average prices paid for materials and labor:

Material:

Lumber for forms, etc., $16.50 per M. ft., B. M.
Cement, Kansas Portland, $1.50 per bbl.
Broken limestone, 45c per cu. yd., Kan.
Sand, Arkansas River, 15c per ton.

Labor:

General foreman, $110 per month.
Assistant foreman, $75 per month.
Timekeeper, $60 per month.
Riveters, 35c per hour.
Blacksmith, 30c per hour.
Blacksmith assistant, 20c per hour.
Carpenters, 22½c and 25c per hour.
Enginemen, 25c per hour.
Firemen, 20c per hour.
Night watchman, 20c per hour.
Laborers, 17½c and 20c per hour.
Team (including driver), 40c per hour.

Note: The prices quoted for lumber, cement, limestone and sand are prices f. o. b., Louisiana, Iola, Kan., El Dorado, Kan., and Wichita, Kan.

The total and unit cost of constructing the concrete piers and abutments and of erecting the steel superstructure are given in the following tabulation. Altogether there was about 2,300 cu. yds. of concrete in the substructure, most of which, as stated above, was a 1-3-5 mixture.

Machinery and Supplies—

Concrete mixer, 20% of cost	$ 152.10
Supplies, freight, hauling, setting up	505.04
Total	$ 657.14
Centrifugal sand pump, 20% of cost	$ 27.00
Supplies, freight, hauling, setting up	277.50
Rent of traction engine to operate	83.25
Total	$ 387.75
Water pump and pipe, 20% of cost	$ 29.00
Supplies, freight, hauling, setting up	177.32
Total	$ 206.32
Pile driver engine, 20% of cost	$ 100.00
Supplies, freight, hauling, setting up	243.65
Total	$ 343.65
Grand total	$1,594.86

Coffer Dams—

Materials, lumber and nails	$1,285.26
Freight and train haul	306.33
Labor making piles	696.82
Labor driving piles	1,384.05
Total	$3,672.46

The sheet piling took 63,500 ft. B. M. of lumber; the cost per 1,000 ft. B. M. for the sheet piling was then:

Materials, lumber and nails	$ 20.08
Freight and haulage	4.82
Labor making piles	10.97
Labor driving piles	21.80
Total	$ 57.67

Forms, Platforms and Runways—

Lumber, hardware, etc	$ 224.59
Freight and train haul	40.20
Labor making, removing and placing	556.51
Total	$ 821.30

Concrete Materials—

Cement, freight, unloading and storing	$4,617.48
Sand, freight, unloading, etc	1,336.05
Broken stone, freight, unloading, etc	2,026.92
Total	$7,980.45

This gives us for 2,300 cu. yds. of concrete a cost of $3.47 per cu. yd. for materials, including freight, storage, and unloading charges of all kinds. A line on the proportion of the cost contributed by these latter items may be got by taking the prices of the materials f. o. b. at the places of production and assuming the proportions for a 1-3-5 concrete. According to tables in Gillette's "Handbook of Cost Data," a 1-3-5 broken stone concrete requires per cubic yard 1.13 bbls. cement, 0.48 cu. yd. sand and 0.80 cu. yd. broken stone. We have then:

1.13 bbls. cement, at $1.50	$1.69
0.48 cu. yd. sand, at 20c	.10
0.80 cu. yd. stone at 45c	.36
Total	$2.15

This leaves a charge of $1.32 per cubic yard of concrete for freight and handling materials. The cost of mixing concrete and placing it in the forms was $3,490.87, or $1.52 per cu. yd. We have then:

Cost of concrete materials per cu. yd	$3.47
Cost mixing and placing concrete	1.52
Total	$4.99

The miscellaneous expenses of the work comprised:

Watchman, tools, telephone, etc	$ 722.48
Shanties, furnishings, supplies, etc	829.04
Total	$1,551.52

To this has to be added $1,134.28, the cost of excavating the coffer dams. The total and unit costs of the different items of the concrete substructure work can now be summarized as follows:

Item.	Total.	Per cu. yd.
Machinery and supplies	$ 1,594.86	$ .69
Coffer dams	3,672.49	1.60
Forms, etc.	821.30	.36
Concrete materials	7,980.45	3.47
Mixing and placing concrete	3,490.87	1.53
Excavating coffer dams	1,134.28	.49
Miscellaneous	1,551.52	.67
Totals	$20,245.74	$8.80

The weight of steel in the plate girders was 694,479 lbs. The total and unit costs were as follows:

Item.	Total.	Per lb.
Steel girders	$19,128.42	2.730 cts.
Freight on girders	1,365.60	0.215
Unloading and stacking	140.35	0.015
Total	$20,634.37	2.96 cts.
Erecting girders	$ 1,363.48	0.211 cts.
Derrick car, 20% of cost	127.10	0.009
Total	$ 1,490.58	0.22 cts.
Grand total		3.18 cts.

The cost of the deck, material, freight, labor and painting was $2,388.42, making the total cost of the superstructure $24.513.37. Adding to this the cost of the substructure, as given above, we have $44,759.11 as the total cost of the bridge. The cost per lineal foot, then, was:

For superstructure	$24.51
For substructure	20.24
Total	$44.75

Cost of Erecting Riveted Deck Girder Bridge.—A riveted deck girder bridge, 710 ft. long and 56 ft. high, consisting of seven 80-ft., one 60-ft. and three 30-ft. sections, was erected as described below. The bridge was to replace 525 ft. of timber trestle and two 105-ft. overhead Howe truss spans on a railway line over which 22 trains were moved between 7 a. m. and 6 p. m. Two travelers with tackle were used in the work. While the excavation was being done the falsework was put in, by trestling the two spans and cutting out a section 1 ft. long of the posts of the trestle part, and introducing an intermediate cap. a distance of 12 ft. below the rail to form lookouts for track for travelers. In this way the cost of the falsework was reduced and everything could be placed from the top. using one traveler for placing the pedestal stones the entire length, and for placing the posts on the return trip. After the posts had been placed the other traveler was erected in order to carry both ends of the girders. Owing to circumstances, the materials were unloaded 2,000 ft. from the bridge and were brought to it on push cars; that is, all except the girders, which were loaded on trucks

and moved with a locomotive. The girders were riveted together on the skids, the ties, tie plates, guard rail and rail placed upon them, and then loaded on trucks ready to be sent out. Jacks were placed under each end of the girders when they had been spotted over their place and they were raised clear of the trucks. The tackle was then attached, a strain taken, the trucks run out, and the jacks released, and they were swung clear. Owing to the height, the stringer-ties and guard rail had to be taken on deck. The bents were let down on the intermediate caps and the girders lowered into place by the means of the lines. It was possible to swing the girders either way, so that when they were within 6 ins. of their seat a small bar, pointed at each end, could be inserted to guide them into place. The first 80-ft. girder was placed in 2 hours and 22 minutes, and the second was placed in 1 hour and 38 minutes, while another girder was placed in 58 minutes. The following costs, incomplete though they are, may be of some value. The work was done some years ago when wages were lower than they now are. Cost of placing the 11 girders, together with the riveting, unloading steel, loading on trucks, engine attendance, etc., was $1,255.49, or $1.7683 per lin. ft.; cost of placing four rocker and three tower bents was $570.04, or $0.8003 per lin. ft.; total cost of superstructure, including falsework and traveler, was $2,248.85, or $3.1674 per lin. ft. The cost of riveting was as follows:

	Rivets.	Per rivet.
Riveting girder	8,026	$0.0502
Riveting bents	480	0.1066
Riveting girders to post	264	0.1458

Cost of an Iron Bridge, Including the Cost of Masonry Abutments.*—In this article we give the cost of erecting a 130-ft. span, supported by stone abutments and pier, at New Buffalo, Mich., for the Chicago & West Michigan Ry., the work being done in 1894.

The statement of the cost of the bridge to the railway company was as follows:

False work material (estimated)	$ 75.00
Ties, etc.	134.86
Iron span	5,568.00
1,050 cu. yds. excavation at $0.25	262.50
425.4 cu. yds. stone (Grafton) at $6.86	2,917.39
445 cu. yds. stone cut and laid at $6.50	2,892.50
Filling behind abutment, laborers	35.25
Filling behind abutments, engine work	5.10
Filling behind abutment, 10% above labor	4.04
Labor taking down old truss and erecting false work	170.75
Labor framing and placing ties and tie guard	67.39
Labor taking down false work	27.00
Total cost	$12,159.78

The actual cost of the stone masonry per cubic yard was $13.05; of this sum $6.50 was for cutting and setting and $6.55 for the stone. The above cost of the stone is the cost to the railway

**Engineering-Contracting,* February, 1906.

company. at La Porte. Delivered at New Buffalo the stone would cost $8.10 per cubic yard, making the actual cost of the masonry $14.60 per cubic yard. The stone measured 425.4 cu. yds. in the block and made 444 cu. yds. in the wall, thus overrunning 19.6 cu. yds. A total of 51 cars of stone was used, the average weight per car being 34,500 lbs.; the average number of cubic feet per car was 226; and the average weight per cubic foot was 144 lbs. These figures were based on the shipping weights of the cars. The stone was scabbled only, which accounts for the high weight per car.

The total cost of erecting the bridge was $265.14, this including the labor for taking down the old truss, erecting false work, framing and placing ties and tie guard, and the labor for taking down the false work. The cost of erecting the 130 ft. span was therefore a trifle over $2 per foot.

It will be noticed that the weight of the iron span is not given in the above statement of the cost of the work, nor is the number of men, the rate of wages or the time employed. The statement would have been much more complete had these details been obtainable.

Cost of a Plate Girder Bridge With Concrete Piers in Mexico.*— The following is rearranged from data originally published in the "Railway Age-Gazette": The bridge consists of 17 spans of 50 ft. deck plate girders carried on concrete piers and reinforced concrete piers and reinforced concrete abutments. The substructure is founded on solid rock ranging in depth below low water from zero on the west shore to 19 ft. on the east shore. The west abutment and succeeding 13 piers were carried to rock; the three remaining piers and the east abutment were set on piles driven to rock and cut off at low water level. The piers consist of bases 14 ft. 9 ins. x 7 ft. 9 ins. in dimensions and varying in height with the depth of foundation, and shafts 13 ft. 9 ins. x 6 ft. 9 ins. at the base; 12 ft. x 6 ft. at the top over coping and 28 ft. high. Each shaft contains about 84.8 cu. yds. of concrete. The spans between pier centers are 50 ft. 3 ins. The abutments are of reinforced concrete.

Two methods of construction were employed. The first method was used for the west abutment and the succeeding six piers. Operations were conducted from the river bed. The west abutment was above water level and was straightforward construction. For this six succeeding piers U. S. Steel Sheet Pile cofferdams were built and excavated; the base forms were set inside and concreted, and then the shaft forms were erected and concreted. A 60 x 120 x 4 ft. barge in the river carried a hoisting engine and stiff leg derrick. This derrick handled the forms and also a clam shell for excavating the cofferdams. A pile driver supported on heavy horses drove the sheeting. The concrete was mixed on the river bed by a ½ cu. yd. Chicago Improved Cube mixer and taken to the work in dump buckets in push cars running on a track

Engineering-Contracting, Feb. 3, 1909.

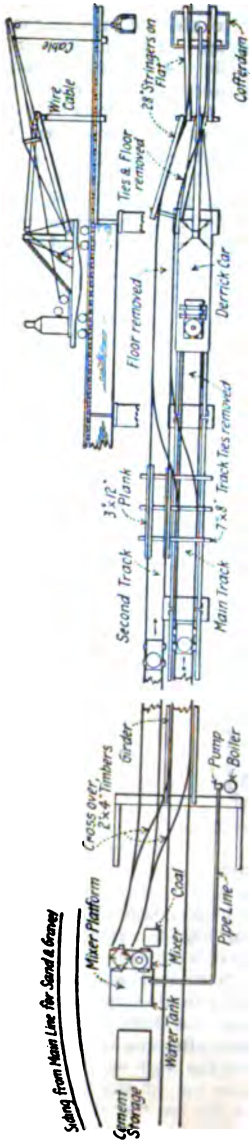


Fig. 6.—Plant Layout.

which was extended from pier to pier. At the piers the buckets were raised and dumped by means of a mast and crosshead. When the pier was completed the girders were set by means of a 15-ton derrick car.

Work was conducted in the manner described from April 20, 1907, to May 1, 1908. This slow progress was due largely to the fact that the organization was such that one part of the work had to await the completion of another, no two operations being carried on at the same time. Furthermore the driving and pulling of the steel sheeting was a tedious process. It took from a week to ten days to drive the sheeting for one cofferdam, and in penetrating the cemented gravel the piles were often so battered and bent that it took as long or longer to pull as to drive them. The excavation of the cofferdam occupied about two days. It was to remedy this slow progress that the second method of construction was devised by Mr. W. W. Colpitts, Assistant Chief Engineer, who assumed personal charge of the work.

A second track was laid parallel to the main track as shown by Fig. 6. To support this second track 20-ft. guard rail timbers were inserted between each pair of main track ties and secured with hook bolts to the girder flanges. On the overhanging ends of these timbers two lines of 3 x 12-in. planks, on 5-ft. centers, were laid to carry the second track rails. The concrete mixed was removed from the river bed and placed on the west bank as shown by Fig. 6; the second track led directly to and from the mixer. A siding was also laid to the mixer for the sand and gravel cars, which were loaded at a nearby cutting. Water was pumped to the mixer from the river as shown by Fig. 6.

The second track was extended from pier to pier as fast as the main track was completed, so that the derrick car could be run out on the second track to a position alongside the last completed pier. The derrick car boom was lengthened about 25 ft. by splicing and trussed with wire cables to sustain a load of 4 tons at its outer end. From the boom a 66-ft. extension of the second track was suspended by cables at the boom and at mid-length; the inner end of the extension track was supported by a bent on the pier. The arrangement of the extension track is made above by Fig. 6; as will be seen the concrete could come from the mixer by car to directly over the pier. When a pier had been concreted the extension track was set one side and detached and the derrick was available for erecting the plate girders.

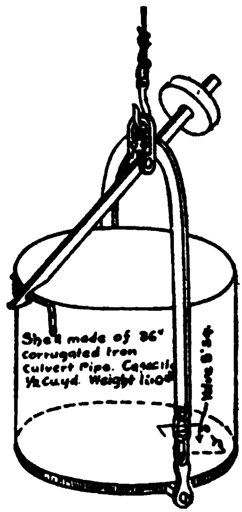


Fig. 7.—Concrete Bucket.

For depositing concrete below water, a bucket was devised to operate with a single line, as illustrated in Fig. 7. It was built of a 3-ft. section of 36 in. corrugated iron culvert pipe, having a capacity of ½ cu. yd. In the bottom, which was of wood, was a clap valve 8 ins. square opening upward A 1-in iron trunnion set 6 ins. off center was secured to the bottom. A bale with chain hooks at its extremities was attached to the pile line of the derrick car which was led through a block at the end of the boom directly over the center of the pier. To the top of the bale was pivoted a counter-weighted trip engaging a lip on the side of the

bucket. The bucket was carried on a push car and the mixer discharged directly into it. It was then run out to the end of the extension, the hooks of the bale slipped over the trunnions, the trip caught on the lip, the bucket raised, and the car pushed from under it. The bucket was then lowered and upon its weight being taken on the bottom the trip automatically released. As the bucket was slowly raised from the bottom and upset, the valve in the bottom opened and the concrete poured out without disturbance; its construction being such that it discharged toward the lowest point. Three buckets were used, one being dumped while two others were on their way to and from the mixer; the loaded car using the second track, the empty car returning on the main track.

The concrete for the shafts was carried in dump boxes on push cars, Fig. 8. The forms were securely wired to prevent distortion from the falling concrete and baffle boards were used to distribute the concrete uniformly.

It was found that detachable cast steel teeth on the lips of the clam shell greatly increased the daily capacity of the dredge and

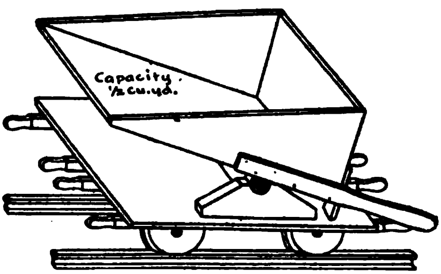


Fig. 8.—Concrete Car.

this fact suggested the advisability of doing away entirely with the steel sheet piling which had proven both expensive and slow. The greatest depth to rock was 19 ft. below the low water surface and was practically level over the area of a pier. It was decided to sink open wooden cofferdams, first dredging as deep as practicable in the open water at the pier site, the limit of which proved to be about 12 ft. In the meantime, the timber for the cofferdams was being framed on the bank. They were built as follows: The three bottom courses were composed of condemned bridge stringers, the lower one having a 45° cutting edge, unshod. Above the stringers the sides were composed of 3x12-in. plank, spiked to corner posts and studs.

During construction the cofferdam was supported on a raft also composed of condemned bridge stringers. The raft was built with an open bay, about 1 ft. larger on all sides than the cofferdam.

Across the center of the opening was stretched a heavy telegraph wire supporting the ends of four planks, the other ends resting on the raft. The lower courses of timbers of the cofferdam were then set in position on these planks and drift-bolted together. The position of the cofferdam on the planks was such that only a small percentage of its weight came upon the wire. The two other courses of stringers were then laid and bolted to these, after which the 3-in. planks comprising the balance of the sides of cofferdam were spiked to the corner posts and studs. When completed, the wire was cut and the cofferdam launched into the water below, which, as stated above, had previously been dredged to a depth of about 12 ft. It was then guyed to its exact position and held level by lines from the boom of the barge derrick. Four posts or legs, with the lower ends resting on the bottom of the excavation, were spiked to the outside corners and all the guys removed, allowing the cofferdam to rest entirely upon these legs. To make provision for weighing the cofferdam while being sunk, stringers were placed across its ends and on the portions projecting beyond the sides, a floor of other stringers was laid and boxed up to a height sufficient to carry a load of about 75 tons of gravel each. The dredging operations were then begun and the material taken from the interior of the cofferdam placed in the boxes until they were filled. When the dredging had continued to a point where the bearing was uniform on the cutting edge of the bottom, the legs detached themselves from the sides and floated to the surface.

By carefully sounding the bottom and loading the boxes uniformly as the dredging proceeded, the cofferdam sank uniformly to the rock. The load was not removed from the boxes until the concrete had been placed, when by cutting the wires supporting the sides the gravel dropped into the water. The cofferdam was prevented from bulging when the concrete was being deposited, by means of a wire cable strung around the top and wedged taut at each of the studs. The derrick car was not removed from its position supporting the extension track until the concrete in both the base and shaft had been placed. The pile line of the derrick car was, therefore, available in removing the form on the shaft of the pier behind and erecting it on the recently completed base. The operation of filling it with concrete was then begun. While the work of placing the concrete in the base, erecting the form for the shaft, filling it and setting the girders was going on, the barge was employed in dredging for and sinking the next cofferdam, and in this manner the work proceeded until the 13th pier was completed.

The piles in the foundations of the three piers on the east bank of the river were driven with rail leads suspended loosely from the boom of the stiff-legged derrick, which had been removed and placed on skids on the bank. The forms were set and filled in the manner described.

The method of building the west abutment was as follows: Upon the completion of the excavation, the form was built up to a point

3 ft. above the bottom of the overhang. The piles were then driven and the back-filling completed up to the level to which the form had been built and care taken to tamp the filling solidly under the form for the overhang. The form was then filled with concrete to the top and the overhanging slab, which was 3 ft. thick, reinforced with steel to enable it to support the load of green concrete that would later come upon it. The form for the upper portion was then completed and the whole filled with concrete up to the bridge seat in two days' run. The west abutment was completed and the last span set on August 27, 1908, an average, after May 1, of one pier and span about every nine working days.

The statement of cost will be especially interesting to those who are familiar with conditions in the Republic of Mexico. Generally speaking, machinery, materials and supplies of all kinds are much more costly than in the United States, but this disadvantage is partly offset by cheap labor. The scale of wages (in U. S. currency) that prevailed on the work are given below:

The cost of materials delivered at the work was as follows:

General foreman	$150.00	per month
Sub-foremen	4.00	per day
Hoisting engineers	4.00	per day
Firemen	1.50	per day
Carpenters	1.50	per day
Blacksmiths	2.00	per day
Laborers (peons)	.75	per day

Cement, per bbl	$ 3.73
For lumber, per M. ft. B. M.	23.33
Bridge timber, per M. ft. B. M.	36.65
Reinforcement, per ton	79.20
Steel sheeting, per ton	54.15
Bridge steel, per ton	69.98

In the statement below a proportion of the cost of all machinery and tools is charged against the bridge, depending upon their condition and availability for future work.

Abutments.

(Contain 586.2 cu. yds. concrete.)

Material.	Total.	Per cu. yd.
Cement, 694.4 bbls., at $3.73	$2,590.11	$4.42
Sand, 263 cu. yds., at $0.50½	132.81	0.23
Gravel, 526 cu. yds., at $0.50½	265.62	0.45
Lumber, 22,232 ft., B. M., $23.33	518.66	0.88
Piles, 240 lin. ft., at $0.22	52.80	0.09
Reinforcement, 41,730 lbs., at $3.96	1,632.51	2.79
Machinery, proportionate cost	59.21	0.10
Wire and nails	101.50	0.18
Lubricating oil	6.50	0.01
Fuel	109.00	0.18
Total material	$5,468.72	$9.33

Labor.

Excavation for foundation	$ 199.66	$0.34
Building and removing forms	331.01	0.57
Driving piles in foundation	67.77	0.11
Placing steel reinforcement	92.55	0.16
Mixing concrete	220.53	0.38
Placing concrete	96.39	0.17
Pumping water	18.74	0.03
Cleaning and storing machines, etc.	61.00	0.10
Total labor	$1,087.65	$1.86
Total material and labor	$6,556.37	$11.19

Bases of Piers 1 to 16, Inclusive.

Bases 1 to 6 contain 373 cu. yds.
Bases 7 to 16 contain 887.7 cu. yds.

Total ....1,260.7 cu. yds.

Material:			Total.	Cu. yd.
Cement, 1,233 bbls., at $3.73			$4,599.09	$3.65
Sand, 591 cu. yds., at $0.50½			298.46	0.24
Gravel, 1,182 cu. yds., at $0.50½			596.92	0.47
Cofferdams of piers 1 to 6:				
Lumber, 3 M., B. M., at $23.33	$ 69.99			
Steel sheet piling	924.72			
Wire nails and oil	53.00			
Machinery	817.00			
Fuel	700.00			
Material in cofferdams 1 to 6		$2,564.71		
Per cu. yd. concrete in bases 1 to 6	$ 6.88			
Cofferdams of piers 7 to 16:				
Lumber, 26 M., B. M., at $23.33	$ 606.58			
Piles in foundation	198.00			
Wire nails and oil	210.25			
Machinery	1,353.66			
Fuel	1,200.00			
Material in cofferdams 7 to 16		$3,568.49	6,133.20	4.86
Per cu. yd. concrete in bases 7 to 16	$4.02			
Total material			$11,627.67	$9.22

Labor:				
Mixing concrete			580.33	0.46
Placing concrete			662.26	0.52
Pumping water			38.00	0.036
Cleaning and storing machines, etc			122.01	0.10
Cofferdams of piers 1 to 6:				
Excavation	$ 857.22			
Driving sheet piling	1,653.19			
Pulling sheet piling	371.60			
Building inside forms	214.21			
Labor on cofferdams 1 to 6		$3,096.22		
Per cu. yd. concrete in bases 1 to 6	$8.30			
Cofferdams of piers 7 to 16:				
Excavation	$1,010.05			
Piles in foundation	313.23			
Building and sinking cofferdams	870.89			
Labor on cofferdams 7 to 16		$2,194.17	5,390.39	4.20
Per cu. yd. concrete in bases 7 to 16	$2.47			
Total labor			$ 6,692.99	$5.31
Total material and labor			$18,320.66	$14.53
Labor and material of cofferdams 1 to 6 per cu. yd. concrete				$15.18
Labor and material of cofferdams 7 to 16 per cu. yd. concrete				6.49

Shafts of Piers, 1 to 16, Inclusive.

(1,357.2 cu. yds. concrete. The shafts of the piers did not differ appreciably in cost, and the statement is not divided as in the case of the bases.)

Materials:	Total.	Per cu. yd.
Cement, 482 bbls., at $3.73	$ 4,617.74	$ 3.41
Sand, 257 cu. yds., at 50½ cts.	321.69	0.24
Gravel, 514 cu. yds., at 50½ cts.	643.38	0.47
Lumber, 3,000 ft., B. M., at $23.33	163.31	0.12
Machinery, proportionate cost	155.00	0.11
Wire and nails	101.50	0.07
Lubricating oil	28.50	0.02
Fuel	919.00	0.68
Total material	$ 6,950.12	$ 5.12
Labor:		
Building and removing forms	$ 582.55	$ 0.43
Mixing concrete	602.45	0.45
Placing concrete	652.79	0.48
Pumping water	39.00	0.03
Cleaning and storing machinery	122.01	0.09
Total labor	$ 1,998.80	$ 1.48
Total material and labor	$ 8,948.92	$ 6.60
Total cost of substructure	$33,825.95	$10.56

Steel Spans.—17 50-ft. Deck Plate Girders.

Material:	Total.	Per ton.
Steel, 611,734 lbs., f. o. b. New York	$16,822.68	$55.00
Freight and brokerage	4,582.68	14.98
Fuel, setting and riveting girders	181.36	0.59
Total material	$21,586.12	$70.57
Labor:		
Unloading and setting girders	$ 294.45	$ 0.96
Riveting girders	640.35	2.09
Setting anchor bolts	105.00	0.34
Machinery, proportionate cost	253.70	0.83
Total labor	$ 1,293.50	$ 4.22
Total material and labor	$22,879.62	$74.79

Deck.—Ties L. L. P. 8-in. x 10-in x 10-ft., Spaced 13-in. Centers; Guard Rails L. L. P., 7-in. x 9-in. x 20-ft.

Material:	Total.	Per M. B. M.
62,401 ft., B. M., f. o. b. Safton, La.	$ 1,123.22	$18.00
Freight and brokerage	1,163.78	18.65
Fuel	25.50	0.40
Total material	$ 2,312.50	$37.05
Labor:		
Framing and placing	$ 561.68	$ 9.00
Machinery, proportionate cost	60.63	0.97
Total labor	$ 622.31	$ 9.97
Total material and labor	$ 2,934.81	$47.02
Total cost of superstructure	$25,814.43	.....
Total cost of bridge	$59,640.38	.....

Cost of Erecting a Draw Bridge of 236-ft. Span.*—This bridge has a span of 236 ft., and a length of 239 ft. over all. Trusses are 16 ft. c. to c., and the depth of truss is uniform and 25 ft. c. to c. of chord pins. The center panel is 16 ft. and the remaining 10 panels are each 22 ft. The bridge is designed to be turned by hand only, and has a drum 22½ ft. x 4¾ ft. The bridge was designed for a live load of 3,300 lbs. per lin. ft.

The total weight of the metal is 433,300 lbs., distributed as follows:

	Lbs.
Trusses	205,600
Lateral bracing	20,000
Floor system	107,000
Turntable—	
Drum (22½ ft. diam.)	21,400
Wheels (46)	16,200
Track	11,100
Rack	4,900
Tread pls.	5,200
Gearing and journal boxes	25,400
End lift	10,200
End supports	6,300
Total	433,300

The itemized cost (to the contractor) of erection was as follows:

General Expense—

7.5 days, foreman at $5.00	$ 37.50
44 days, bridgemen, at $3.00	132.00
34 days, laborers, at $2.00	68.00
10 days, watchman, at $2.00	20.00
3 days, blacksmith, at $3.00	9.00
98.5. Total labor, at $2.67	$266.50
3,000 ft. B. M. in traveler at $25	75.00
Total	$341.50

This $341 includes the cost of erecting a derrick to unload the steel from cars, the labor of making and erecting traveler.

Erection of Steel Work—

19 days, foreman, at $5.00	$ 95.00
110 days, bridgemen, at $3.00	330.00
80 days, riveters, at $3.00	240.00
73 days, heaters and buckers, at $2.00	146.00
84 days, laborers, at $2.00	168.00
366. Total laborers, at $2.65	$ 969.00
30 days' rent of hoisting engine, at $3.00	90.00
10 tons coal, at $3.00	30.00
Total	$1,089.00

**Engineering-Contracting*, May 29, 1907.

The engineman received the same wages as the bridgemen and was classed with them.

3 days, foreman, at $5.00	$ 15.00
9 days, bridgemen, at $3.00	27.00
80 days, painters, at $2.50	200.00
92 days total labor	$242.00
Total materials and labor	$337.00

Timber Deck (17,000 ft. B. M.)—

3 days, foreman, at $5.00	$15.00
26 days, carpenters, at $2.75	71.50
3 days, laborers, at $2.00	6.00
32 days total labor at $2.90	$92.50

It will be noted that the labor of framing and placing the timber deck (i. e., the ties, guard rail, etc.) cost $5.50 per M, or 38 cts. per lin. ft. of bridge.

There is clearly some error in the amount of red lead and oil above given. Since the bridge weighed 433,000 lbs., or 216.5 tons, the cost per ton for erection may be summarized as follows:

		Per ton.
General Expense—		
Labor	$ 266.50	$1.23
Material for traveler	75.00	0.35
Erecting Steel—		
Labor	$ 969.00	$4.49
Rent of engine	90.00	0.42
Coal for engine	30.00	0.14
Painting—		
Materials	$ 95.00	$0.44
Labor	242.00	1.11
Timber deck	92.50	0.42
Total	$1,860.00	$8.60

This work was done by a contractor who received $12 per ton for erecting the bridge. Practically no falsework was necessary, since the bridge was erected upon the "draw protection," which served as a falsework.

The bridge metal cost 4 cts. per lb. f. o. b. cars, ready for erection, and, since the contract price was 0.6 cts. for erection, the total was 4.6 cts. per lb. in place, or $19,931 for the total superstructure, exclusive of the timber deck. This is equivalent to nearly $85 per lin ft. There were nearly 70 ft. B. M. per lin. ft. of timber deck (ties and guard rail), which cost $20 per M, or $1.40 per lin. ft. of bridge.

Cost of Howe Truss Bridges, Cross-References.—In the section on Timberwork will be found other data on Howe truss bridges.

Cost of a 150-ft. Howe Truss Bridge.—The following data were published in *Engineering-Contracting*, June 26, 1907. While the old-fashioned Howe truss railway bridge is no longer built in the eastern part of America, it is still to be found in the West, and is likely to remain in use, here and there, for many years to come. Practically nothing has ever found its way into print as to

the cost of erecting Howe truss bridges, hence the following data should be of value to many of our readers.

A railway Howe truss through span bridge of 150 ft. span, was erected by company forces at the following cost:

Loading Bridge Material—		
2 days, foreman, at	$3.00	$ 6.00
18 days, carpenter, at	2.50	45.00
12 days, helper, at	2.00	24.00
32 days. Total	$2.34	$75.00
Loading Hoisting Engine—		
0.5 day, pile driver engr., at	$3.00	$ 1.50
0.15 day, carpenter, at	2.50	3.75
0.5 day, helper, at	2.00	1.00
2.5 days. Total	$2.50	$ 6.25
Loading Pile Driver—		
1 day, carpenter	$2.50	$ 2.50
1 day, helper	2.00	2.00
2 days. Total	$2.25	$ 4.50
Fitting Up Pile Driver—		
13.5 days, carpenter	$2.50	$33.75
3.5 days, helper	2.00	7.00
17 days. Total	$2.40	$40.75
Driving Pile Falsework—		
1 day, foreman	$3.00	$ 3.00
1 day, engineer	3.00	3.00
8 days, carpenter	2.50	20.00
5 days, helper	2.00	10.00
15 days. Total	$2.40	$36.00
Framing and Erecting Bridge—		
30 days, foreman	$3.00	$ 90.00
22 days, engineer	3.00	66.00
236 days, carpenter	2.50	590.00
260 days, helper	2.00	520.00
548 days. Total	$2.30	$1,266.00
Train Service—		
2 days, conductor	$3.50	$ 7.00
4 days, brakeman	2.50	10.00
2 days, locomotive and crew	25.00	50.00
Total		$67.00
Miscellaneous—		
11 tons coal for hoisting engine, at $3		$ 33.00
Repairs to hoisting engine		24.00
Tools, etc.		135.00
Total		$192.00
Bridge Materials—		
88,800 ft. B. M. timber, at $15		$1,332.00
44,800 lbs. wrought iron, at 2½ cts.		1,120.00
40,000 lbs. cast iron, at 1.8 cts.		720.00
Total		$3,172.00

Falsework Material—

1,120 lin. ft. piles (28 piles, 40 ft.), at 8 cts	$ 89.60
30,000 ft. B. M., second hand, at $8.00	240.00
500 lbs. iron, at 2½ cts	12.50
Total	$242.10

Pile Abutments Material—

1,600 lin. ft. piles (40 piles, 40 ft.), at 8 cts	$128.00
1,700 lbs. iron, at 2½ cts	42.50
7,600 ft. B. M., at $15	114.00
Total	$284.50

Pile Abutment Labor—

5 days, foreman, at	$3.00	$ 15.00
5 days, engineman, at	3.00	15.00
36 days, carpenter, at	2.50	90.00
30 days, helper, at	2.00	60.00
76 days. Total	$2.37	$180.00

SUMMARY.

Labor—

32 days, loading material, at	$2.34	$ 75.00
2½ days, loading engine	2.50	6.25
2 days, loading pile driver	2.25	4.50
17 days, fitting up pile driver	2.40	40.75
15 days, driving falsework	2.40	36.00
548 days, erecting bridge	2.30	1,266.00
2 days, train service	....	67.00
76 days, building pile abutments	2.37	180.00
Miscellaneous supplies		192.00
Total labor and supplies		$1,867.50

Materials—

Falsework material	$ 242.10
Abutment material	284.50
Bridge material —	
88,800 ft. B. M., at $15	1,332.00
44,800 lbs., wrought iron, 2½ cts	1,120.00
40,000 lbs. cast iron, 1.8 cts	720.00
Total material	$3,698.60
Total labor and material	$5,566.10

The abutments were not protected by cribs, nor is any riprap included in the above cost. In subsequent issues we shall give costs of abutments protected by cribs and riprap.

The cost per lineal foot of bridge was as follows:

Labor—		Per lin. ft.
General labor, loading materials, etc.	$ 162.50	$ 1.08
Erecting bridge	1,266.00	8.44
Train service	67.00	0.45
Building pile abutments	180.00	1.20
Miscellaneous supplies	192.00	1.28
Total labor		$12.45
Material—		
Falsework	$ 242.10	$ 1.61
Abutment	284.50	1.90
Bridge	3,172.00	21.15
Total material		$24.66
Total labor and material		$37.11

It will be noted that the cost of fitting up the pile driver ($40.75) was excessive; but, on the other hand, the cost of driving the pile falsework ($36) was low.

The cost of framing and erecting the bridge ($1,266) includes the cost of erecting the upper falsework.

The labor on the pile abutments ($180) was high, considering there were no cribs.

Cost of Two Howe Truss Bridges of 120-ft. and 130-ft. Span, Including Falsework and Pile Abutments.*—The following data relate to a through Howe truss bridge 130 ft. long over all, for which a contract was let for the labor of erecting the bridge. The contractor paid bridge carpenters $2.75 a day and helpers $2.00

The bridge was designed for a live load of engine and tender weighing 112 tons, followed by a train of 3,000 lbs. per lin. ft. The dead load was 1,650 lbs. per lin. ft.

The cost of the bridge to the railway company was as follows:

Falsework—	
840 lin. ft. piles (20 piles) delivered at 8 cts...	$ 67.20
840 lin. ft. piles driven at 12 cts.	100.80
24,000 ft. B. M. timber delivered at $15.	360.00
24,000 ft. B. M. timber framed and erected at $7.50	180.00
400 lbs. iron at 25 cts.	10.00
Total, $5.52 per lin. ft. bridge.	$ 718.00
Pile Abutments—	
1,400 lin. ft. piles (40 piles, 35 ft.) delivered at 8 cts.	$ 112.00
1,400 lin. ft. piles, driven, 12 cts.	168.00
1,700 lbs. iron, 2.5 cts.	42.50
7,600 ft. B. M. timber delivered, $15.	114.00
7,600 ft. B. M. framed and erected, $7.50.	57.00
Total for two abutments.	$ 493.50
Howe Truss Bridge—	
29,000 lbs. cast iron, at 2 cts.	$ 580.00
34,000 lbs. wrought iron, 2½ cts.	850.00
71,700 ft. B. M. timber, at $15.	1,075.00
130 lin. ft. bridge framed and erected, at $7.50...	975.00
Total	$3,480.00
Train service.	50.00
Total	$3,530.00
Summary—	
Falsework, materials.	$ 437.20
Falsework, labor (by contract).	280.80
Pile abutments, materials.	268.50
Pile abutments, labor.	225.00
Howe truss bridge, materials.	2,515.00
Howe truss bridge, labor.	975.00
Train service.	50.00
Grand total, 130 lin. ft., at $36.50.	$4,751.50

It will be noted that there was no crib, crib filling or riprap protection for the abutments. It would not be excesive to add 400 cu. yds. of riprap and rock in cribs, at $1.50 per cu. yd., and 24,000 ft.

**Engineering-Contracting,* July 3, 1907.

B. M. (or 2,000 lin. ft.) of hewed timber for two cribs to protect the abutments. A common contract price in the West is 15 cts. per lin. ft. of crib timber in place.

The full cost of the timber for the falsework in this bridge is charged against the bridge, but, since most of it possesses a salvage value, not to exceed half the cost of the timber (half of $360) should be so charged.

It will be noted that the contract price of framing and erecting the bridge was $950, which is equivalent to about $14 per M. ft. B. M. in the bridge, exclusive of the falsework. The falsework cost $718, which, if added to the $975, gives a cost of $1,693, or $13 per lin. ft. of bridge.

The piles for the falsework were driven in bents about 11 ft. apart, two piles to the bent. While this is a sufficient support for the dead load of a Howe truss bridge, it is evidently insufficient to support any trainload during construction. In rebuilding an old bridge, without interruption to traffic, it is evident that the falsework would be much more expensive than in this case, which is typical of new construction rather than of reconstruction.

The following costs relate to a Howe truss bridge 120 ft. long, and the remarks concerning the 130-ft. bridge apply also to this one:

Falsework—	
540 lin. ft. piles (18 piles) delivered at 8 cts..	$ 43.20
540 lin. ft. piles driven, 12 cts.	64.80
28,000 ft. B. M. at $15	420.00
28,000 ft. B. M. framed and erected, $7.50	210.00
400 lbs. iron, 2.5 cts.	10.00
Total at $6.23 per lin. ft. bridge	$ 748.00
Pile Abutments—	
Same as for previous bridge	$ 493.50
Howe Truss Bridge—	
63,000 ft. B. M. at $15	$ 945.00
28,400 lbs. wrought iron at 2.5 cts.	710.00
25,400 lbs. cast iron at 2 cts.	508.00
120 lin. ft. framed and erected, $7.50	900.00
Total	$3,063.00
Train service	50.00
Summary—	
Falsework, materials	$ 463.20
Falsework, labor (by contract)	274.80
Pile abutment, materials	268.50
Pile abutment, labor	225.00
Howe truss bridge, materials	2,163.00
Howe truss bridge, labor	900.00
Train service	50.00
Grand total, at $36.20 per lin. ft.	$4,344.50

As previously stated, no protection cribs, rock filling, or riprap are included in the cost of the abutments.

Cost of Constructing Six Crib Piers, Three Howe Truss Spans and One Steel Draw Span.*—Crib piers for railway and highway bridges possess the great merit of making it unnecessary to build coffer

**Engineering-Contracting*, July 24, 1907.

dams, and, on this account, have always been popular with Western engineers. During recent years, however, concrete piers, built within coffer dams, have become more common than crib piers. Nevertheless, there are many places where the crib pier is still the most economic pier that can be designed.

The bridge to be described in this article consists of three Howe truss spans of 150-ft. each, and a steel draw span almost 300-ft. long. It crosses a Washington river near its mouth, where the tidal currents cause a daily rise and fall of several feet. The river is 19 ft. deep at extreme low tide, and the top of the piers is 40-ft. above the river bed.

With the exception of the pivot pier, which will be described separately, the piers were crib piers resting on piles. A description of the construction of one of these five piers will serve for the rest.

Crib Pier.—Each pier is supported by 52 piles driven 3 ft. c. to c. to a depth of 30 ft. Piles 60 ft. long were necessary, due to the depth of the water at high tide, and were sawed off 7 ft. above the bottom of the river, or 12 ft. below extreme low water. The driving was very hard, the bottom being of sand in which the average penetration of the pile was only 2 ins. under the blow of a 2,200-lb. hammer falling freely 20 ft. For sawing off the piles, a circular saw on a 40 ft. vertical shaft was used. The shaft was rotated by an engine mounted on a carriage movable in any direction on two tracks at right angles to each other, one track being above the other.

While the piles were being driven for a pier, the crib was constructed. Each crib consisted of a bottom, or floor, made of three solid courses of 12 x 12-in. timbers drift-bolted together, and on top of this bottom was built the crib proper. The bottom was built on shore and then launched. Then the crib was built of 12 x 12's log-house fashion, on top of the "bottom" until it reached a height of 12 ft. The crib was then floated over the rest of foundation piles, and arrangements made to lower it upon the piles. To insure a steady and even lowering of the crib, without risk of capsizing, it was necessary to lower the crib by means of blocks and tackle fastened to two bents of guide piles, one bent on each side of the crib. Rock was dumped into the crib, and it was sunk until it rested on the piles. This left the upper course of timber above the level of low water, and in readiness to continue the building up of the crib to the desired height. The cribs were designed so that the load of the bridge came directly upon the rock filling in the crib, the intention being to build masonry upon the rock fill after the crib timbers above the water level have rotted out.

In this connection it is interesting to note that the crib timbers were compressed nearly 1-16 in. per ft. of height, after the load came upon the piers. Part of this compression was doubtless due to shrinkage of the timber upon drying.

We would offer a suggestion as to a possible improvement in this form of crib pier construction. Let the foundation piles and the crib be built, in the manner above described, up to the low water level. But from that level to the top of the pier, substitute rein-

forced concrete "timbers" in place of wood. These concrete "timbers" could be cast on shore, and made so as to interlock, forming a solid and durable outside wall. Loose rock filling and gravel could then be deposited inside this wall, thus giving the necessary stability to withstand the impact of ice and drift. A pier of this sort would be far cheaper than a solid masonry pier, but would possess sufficient stability and a durability equal to that of solid masonry. In pier building, it should be remembered, the engineer seeks to secure a mass that will resist impacts rather than a monolith of great strength.

Returning now to the methods used in this crib pier construction, one feature is worthy of particular note. A crib having a height two or three times greater than its width is very "cranky" when floating in the water. It tends to turn over, and this tendency is made serious where the tides are rising and falling. It was necessary to have one man in constant attendance day and night, tightening or loosening the guy-lines with the changes of water level.

Before placing the crib pier over the piles, riprap was deposited between them, and leveled off by a diver. After the crib pier was in place, riprap was piled all around the pier to a depth of 6 ft. above the river bottom.

The Pivot Pier.—This pier differed from the piers just described in that it was a stone masonry pier resting on a timber grillage on top of piles. There were 121 piles, driven 3 ft. c. to c., forming a square 32 ft. on a side. The piles were sawed off only 18 ins. above the river bottom.

Sawing them off so close to the bottom was a mistake, for it entailed a great deal of trouble in placing the grillage upon the piles. This was due to the fact that dirt lodged upon the tops of the piles after they were sawed off, making it necessary for a diver to clean the piles off. The driving of the piles 3 ft. c. to c. caused the bottom to rise 6 to 12 ins. Then the eddies formed by the projecting pile heads and by the draw protection caused the floating sediment in the river to deposit around and on top of the piles. To add to the difficulty, the contractor had unfortunately deposited some of the riprap immediately after driving the piles, and many of the stones had lodged on top of the piles.

In this connection we recall a similar experience arising from the deposition of sand around the piles while they were being sawed off, dulling the teeth of the saw and adding greatly to the expense of cutting off the piles. The eddy caused by the piles of the draw protection was largely accountable for the trouble. Finally a V-shaped wing dam of boards was built in the draw protection immediately above the site of the pier, and it served to divert the stream of sand and gravel that is constantly rolling along the bottom of a swiftly flowing river.

The lesson learned by such experiences is simple: Do not cut off piles less than 2 ft. above the bottom of a river, unless there is some excellent reason for so doing.

The grillage built for this pivot pier was 32 ft. square and 15 ft. high, made of 12 x 12-in. timbers laid solid and drift-bolted together, except in the three upper courses where the timbers were laid 2 ft. apart, and the space filled with concrete.

At the bottom of the grillage, two timbers in each course projected beyond the others, so that guy lines could be fastened to them, by which the pier was kept balanced during construction while floating on the rising and falling tides. The guy lines were fastened to two pile bents, one on each side of the pier, which, together with the pile bents of the draw protection, formed a square enclosure in which the pier was guided to the bottom.

Of course the grillage sank under the weight of the masonry which was built on top of it. This masonry was laid inside on "open caisson" built on top of the grillage, the "caisson" being octagonal in shape, made of 3-in. plank, and 16 ft. high. The plank was beveled on the outer edges to provide caulking seams. Two small gates were provided in the "caisson," so that, when the pier had set properly on the piles at low tide, water could be let into the "caisson" and left there until the pier was finished. Then the gates were again closed, the water pumped out, and the masonry was painted.

Cost of the Piers.—The labor cost records were not kept in as great detail as one might wish, yet they possess considerable value. The quantities of materials and contract prices, however, will serve as an excellent guide, and are as follows:

3,120 lin. ft. piles (52) delivered at...	$ 0.08	$ 249.60
3,120 lin. ft. piles driven at..........	0.20	624.00
54,000 ft. B. M. delivered at..........	15.00	810.00
54,000 ft. B. M. framed and placed.....	11.00	549.00
4,000 lbs. iron at....................	0.03	120.00
8 guide piles delivered at........	3.00	24.00
4,000 ft. B. M. falsework at..........	15.00	60.00
190 cu. yds. rock (crib fill).......	2.00	380.00
580 cu. yds. riprap at..............	2.00	1,060.00
5 cu. yds. concrete at............	8.00	40.00
Total		$3,961.60

This is equivalent to $100 per lin. ft. of height of pier, since the piers were 40 ft. high above the bed of the river.

Cost of Pivot Pier.

7,260 lin. ft. piles (121) delivered at.	$0.08	$ 440.80
7,200 lin. ft. pile driven at.........	0.20	1,452.00
162,800 ft. B. M. delivered at.........	15.00	2,442.00
162,800 ft. B. M. placed at............	8.00	1,302.40
7,200 lbs. iron at..................	0.03	216.00
16 guide piles at.................	3.00	48.00
13,200 ft. B. M. falsework at........	15.00	198.00
318 cu. yds. masonry at..........	15.00	4,770.00
570 cu. yds. riprap at.............	2.00	1,140.00
Total		$12,009.20

This is equivalent to $300 per lin. ft. of height of pier.

The contract price for driving the piles, 20 cts. per lin. ft., was high, considering the length of the pile, for it amounted to $12 per

pile. But the driving was very hard, and the price for driving included cutting off the piles below water. It required 26 days to drive the 121 piles in the pivot pier and 10 days more to cut them off. Had a water jet been used the driving would have cost much less. The average rate and wages paid by the contractor for the pile driver crew was $2.50 per day. If a crew of 6 men, a pile driver engineman and a foreman were required, the wages and fuel amounted to $25 a day. Hence if 5 piles were driven per day the cost was $5 a pile. Since 12 piles were sawed off per day the cost of sawing was more than $2 per pile. No detailed records of the actual cost to the contractor are available further than that it required 3,800 days' labor at $2.50, or $9,500, to drive the piles, frame and place the timber, place the crib, fill the riprap for all the piers and lay the masonry. The stone for the masonry was delivered cut ready to lay. The riprap was delivered on scows and measured on the scows before placing.

The Howe Truss Spans.—Three Howe truss spans, each 150 ft. long, and one steel draw span, 293 ft. long, were built as follows:

These Howe truss bridges were erected on a pile falsework, each span having six bents of three 60-ft. piles to a bent. The outside piles of each bent were drawn in 4 ft. at the top and well braced to withstand the action of the deep swift river.

To protect the falsework against drift wood a temporary log boom was placed on the upstream side of the bridge during erecting.

After the bridge was erected, the falsework piles were broken off at the bottom of the river.

The railway company furnished all the material for the falsework, as well as for the bridge. The contract price of $9 per lin. ft. of bridge covered the labor cost of erecting and removing the falsework, as well as framing and erecting the bridge. The cost of each of the 150-ft. Howe truss bridge spans was as follows:

88,600 ft. B. M. in bridge at $15	$1,329.00
45,600 lbs. wrought iron at 3.5 cts.	1,576.00
38,800 lbs. cast iron at 2.5 cts.	970.00
1,080 lin. ft. piles (18) in falsework at 8 cts.	86.40
4,000 ft. B. M. in falsework at $15	60.00
Erecting 150 ft. at $9	1,350.00
Total	$5,391.40

This is equivalent to $36 per lin. ft. of bridge, exclusive of the piers and abutments.

There was no profit to the contractor at the $9 per lin. ft. for erection, for it required 400 man-days per span. The average wages paid were $3.30 per day. Hence the labor cost $1,320 to erect the falsework and the Howe truss span. In our issues of June 26 and July 3 we have given in detail the labor cost of erecting similar bridges where the cost of erection was considerably less than in this instance. (See pages 1529 and 1532.)

The Steel Draw Span.—The span was 293 ft. long, and weighed 265 tons. The steel was unloaded from cars into a material yard and conveyed on scows to the "draw protection," where it was erected by means of a traveler.

The draw protection was built in the usual manner, consisting of pile bents 10 ft. apart, three piles to the bent, each pile being 70 ft. long. A log boom was built entirely around the draw protection, the opposite sides of the boom being held together by cross logs between the 2d and 3d bents and between the 6th and 7th bents. The boom was made of sticks 60 ft. long, held together with ¾-in. chains and shackles.

The cost of the draw protection was as follows:

5,180 lin. ft. piles (74) at 8 cts.	$ 414.40
40,900 ft. B. M. timber at $15	613.50
2,800 lbs. iron at 3 cts.	76.00
680 lin. ft. of boom sticks at 8 cts.	54.40
3,900 ft. B. M. timber wasted and in staging at $15	58.50
Driving 74 piles at $6.00	444.00
Framing and placing 40,900 ft. B. M. at $8	327.20
Total	$1,988.00

After the erection of the draw protection and the traveler and falsework, it required 38 days to erect the steel draw span.

In order to make sure that the panel sections of the top and bottom chords would come together before riveting, both ends of the draw bridge were jacked up after being erected and while temporarily held together with bolts. This brought all the joints of the top chord together, and, after riveting the entire top chord, the false work was knocked out, and in a suspended position the bottom chord was forced together and riveted. However, when the bridge was swung, it was found that the dead load was sufficient to cause the ends of the draw to sag to such an extent that they were 1¼ ins. below the proper level. This made it necessary to lower the pedestals on the rest piers a corresponding amount.

The cost of the draw span was as follows:

530,000 lbs. steel at 4.3 cts.	$22,802.90
21,100 ft. B. M. ties and guide rail $15	316.50
Paint	380.00
Laying timber deck, 100 days, at $3.30	330.00
Erecting bridge, including materials and labor on falsework (by contract)	1,750.00
Total	$25,579.40

This is equivalent to $87 per lin. ft. of bridge, not including the cost of the piers and the draw protection.

The timber deck was laid as an "extra work job" by force account, and the labor cost at least twice what it should have cost, as can be seen by reference to costs of similar work in our issues of April 17, May 8, and May 29. (See pages 1501 and 1506.)

The contractor received only $1,750 for erecting this 265-ton bridge, or $6.60 per ton. It actually cost him nearly $8.15 per ton for labor alone, for it took 800 man-days at $2.70, or $2,160, to erect the traveler, the falsework, and the bridge. It took 60 man-days to paint the bridge, at $3.30 per day, or $198, which is

equivalent to 75 cts. per ton, making a total of $8.90 per ton for the labor of erecting and painting.

No record of the cost of falsework for this draw span is available, but it was a comparatively small item, for no lower falsework is necessary where a draw bridge is erected on the draw protection.

Cost of the Frazer River Bridge.—The Frazer River bridge at New Westminster, B. C., was built in 1902. It is a double deck bridge, the upper deck for wagon traffic and the lower deck for steam and electric traffic. The spans are as follows: One 225 ft., one 380 ft., and one swing span 380 ft., five spans 159 ft. each, making a total of 1,780 ft. On the north end there are three approaches, two for railway tracks and one for highway, the length of approach averaging about 300 ft. The clear roadway is 16 ft. wide, making the trusses 18 to 19 ft. c. to c. The weight of steel is 6,854,000 lbs., and there are 765,000 ft. B. M., and 15,000 lin. ft. piles in approaches. The contract price for substructure and superstructure was $750,000.

Estimates of the Cost of Combination and All-Steel Highway Bridge of 190-ft. Span.—Mr. H. G. Tyrrell gives the following:

The bridge in question was a single span structure designed for the Pacific Coast. The trusses were to be pin-connected with 10 panels of 19 ft. each, and inclined top chord. The principal dimensions and specified loads were as follows:

Span, 190 ft. c. to c.

Roadway, 24 ft.

Two walks, each 6 ft. wide.

Total width of bridge, 41 ft.

Depth of trusses, 27 ft. to 33 ft.

Floor, 4-in. wood block paving on 3-in. plank, laid on wood joints.

Uniform live load on floor, 100 lbs. per sq. ft.

Concentrated load on floor, 15-ton roller or two electric cars on each track.

Live load, per lin. ft. of bridge, 3,300 lbs.

Dead load, per lin. ft. of bridge, 2,345 lbs.

For the "combination" design, hard pine was used for top chords, web posts, portals, lateral struts, floor beams and joists. The remaining parts were of steel.

The estimated quantities for this case were:

Eye-bars	42,180	lbs.	
Cast-iron joint blocks	19,720	"	
Lateral rods	5,810	"	
Machined work	5,940	"	
Shoe plates	5,200	"	
Loops	3,160	"	
Hangers	1,240	"	
Total	83,250	lbs.	Cost $ 3,130

Hard pine chords and posts	17,500 ft. B. M.			
Hard pine lateral struts	3,080 " "			
Floor plank	19,740 " "			
Floor joists	22,240 " "			
Floor beams	14,800 " "			
Total	77,360 ft. B. M.	Cost	$	2,400
Paving 504 sq. yds.		"		750
Fence, 400 lin. ft.		"		200
Erection		"		1,200
Total cost of combination span = about $1 per sq. ft. of total floor		Cost	$	7,680

For the all-steel design the quantities were:

Steel, 180,000 lbs.	Cost	$	7,360
Floor plank, 19.74 M; wood joist, 22.24 M	"		1,435
Fence, 400 lin. ft.	"		200
Paving, 504 sq. yds.	"		750
Erection	"		1,200
Total cost of steel span, about $1.43 per sq. ft. of total floor	Cost		$10,945

The above estimates are for the entire superstructure in each case. If we compare now the cost of the substituted parts only, we have in the combination design, the top chords, web posts, portals, lateral struts and floor beams contain:

Hard pine, 35.3 M, at $35 M	$1,220
Cast iron joint blocks, 19,700 lbs., at 3 cts.	591
Total	$1,811

For the all-steel design the same parts contain:

Steel, 118,200 lbs., at 4 cts. $4,720

Summarizing, we have:

Combination bridge	Cost	$	7,680
Steel bridge	"		10,945
Combination chords, etc.	"		1,811
Steel chords, etc.	"		4,720

Hence, we say roughly that the combination bridge cost one-third less than the steel one. Also that the comparative cost of wood (including necessary cast-iron blocks), and steel for top chords, web posts, portals, lateral struts and floor beams, is as 1 to 3.

Cost of a 300-ft. Highway Drawbridge.—A highway drawbridge across the Harlem River, 3d Ave., New York city, was begun in 1893 and finished in 1896. The span is 300 ft. long; the width is 87½ ft. over all. There are four lattice trusses. The three carriage ways are each 20 ft. wide, and the two sidewalks are each 9 ft. wide carried on cantilever brackets. The floor is of buckle plates covered with concrete and asphalt pavement. The bridge weighs 2,500 tons, and is carried on a 50-ft. turntable. The time required for a full opening is 2 mins. and 2 mins. more for closing and locking. A 50-hp. engine does the work, but a duplicate power plant is provided.

The contract price was $1,111,000 for the bridge complete, which is $47 per sq. ft. of roadway and sidewalks. This is a very high cost. The total cost, including lands, was more than $2,000,000.

The following are some of the important quantities and bidding prices:

	Unit prices.
107,500 ft. B. M. yellow pine in temporary bridge	$40.00
200,000 ft. B. M. hemlock in temporary bridge	30.00
5,000 cu. yds. pneumatic caissons including concrete filling	29.00
Portland cement concrete, cu. yd	9.00
Natural cement concrete, cu. yd	5.40
Granite Ashlar facing below low water, cu. yd	14.00
Granite Ashlar facing above low water, cu. yd	20.00
Granite caps, cu. ft	2.50
Granite coping, cu. ft	3.00
Granite columns, capitols and bases	2.00
Granite dimension, in rough bases	0.50
Rough pointing, sq. ft	0.40
Fine pointing, sq. ft	0.50
Four-cut axing, sq. ft	0.50
Six-cut axing, sq. ft	0.60
Eight-cut axing, sq. ft	0.70
382,000 lbs. rolled steel and iron in turntable	0.048
1,692,000 lbs. rolled steel and iron in draw span	0.039
1,386,000 lbs. rolled steel and iron in deck spans	0.037
4,200 lbs. corrugated plates, deck spans	0.034
357,000 lbs. buckle plates, draw spans	0.032
282,000 lbs. steel plate girders	0.033
420,000 lbs. steel rolled beams	0.026
117,800 lbs. castings in wheels	0.07
126,000 lbs. castings hub and bed plates	0.05
2,000 lbs. other iron castings	0.025
35,000 lbs. steel plates or angles	0.025

Cost of a Steel Arch Bridge.—The Cambridge Bridge across the Charles River (Boston) was built in 1901. It is a highway bridge, 1,768 ft. long, consisting of 11 spans of steel arches (of 12 ribs each), having spans varying from 101 to 188 ft. The height at the center is 48 ft. above low water. The bridge is 105 ft. wide between railings. From the bottom of the piles to the surface of the roadway is 100 ft. The construction involved 80,000 cu. yds. dredging, 85,000 cu. yds. concrete, 20,000 cu. yds. granite, 25,000 piles and 16,000,000 lbs. steel. The estimated cost is $2,500,000, or $1,400 per lin. ft., or $14 per sq. ft.

Cost of Red Rock Cantilever Bridge.—Mr. S. M. Rowe gives the following data relative to this bridge, which was built in 1889 across the Colorado River in Arizona for the Atlantic and Pacific R. R. Co. (See p. 1616 for the cost of the caisson.)

The bridge was designed for a live load of two engines, each weighing 188,000 lbs. (including 74,000-lb. tender), concentrating 46 tons on a wheel base of 11 ft. 9 ins., followed by a train of 3,000 lbs. per ft.

The length of the cantilever bridge is 990 ft.; the span between the piers being 660 ft., and each anchor arm being 165 ft.

The following is the weight of metal in the bridge:

	Lbs.
East anchorage, exclusive of floor beams	78,435
West anchorage, exclusive of floor beams	92,488
Floor of anchor and cantilever arms	271,510
Two anchor arms	969,870
Two cantilever arms	969,870
Metal over piers (posts, etc.)	178,790
Expansive panels (chords and X posts)	128,170
Temporary members (wedges, reinforced bars)	76,040
Suspended span	701,975
Total	3,416,618

About 70% of this was steel and 30% iron.

The cost of this superstructure was as follows:

Iron and steel erected (including freight)	$213,537.83
Timber	1,684.68
Tools and materials	625.58
Fuel and water	1,340.94
Local and train service	1,202.78
Labor in addition to contract work	2,138.79
Engineering	9,624.14
Total	$230,154.74

The cost of the substructure was as follows:

Caisson (see page 1617 for details)	$128,263.19
Masonry piers and abutments	80,267.65
Preparatory	23,748.10
Total	$232,278.94
Grand total	$462,433.66

This is equivalent to $463 per lin. ft.

The "preparatory" work consisted of the following items:

Soundings	$ 7,808.79
Trestle and tracks to caisson	6,238.17
Track to quarry	7,313.58
Freight	525.15
Demurrage	900.00
Engineering	962.41
Total	$23,748.10

The cost of this bridge was unusually high.

Estimated Cost of a Cantilever Bridge and of a Suspension Bridge Across the St. Lawrence.—In 1896 the Montreal Bridge Company received competitive plans and estimates for a proposed bridge across the St. Lawrence River at Montreal. The bridge was specified to be one channel span of 1,250 ft., two side spans of 500 ft. each, 15 steel viaduct spans on south approach of 250 ft. each, 18 viaduct spans on north approach of 60 to 240 ft. each, the clear headway in the channel span to be 150 ft. The bridge was to be for a double track steam railway, two street railway tracks, a carriageway and two sidewalks. The piers of the cantilever were to be of masonry.

The prize plan was submitted by Edward S. Shaw of Boston. ˜e increased the side spans to 600 ft. The bridge was designed

to be 80 ft. wide, with four trusses. The stone sub-piers are each 30 x 110 ft. in plan on top, 60 ft. above low water, surmounted by steel piers 230 ft. high. The middle roadway is 26 ft. wide and is for the double track railway; the two side roadways are each 21½ ft. wide; flanked by 6-ft. sidewalks on brackets. The estimated weight of structural steel was:

	Lbs.
Main cantilever and central span	39,460,000
South viaduct approach	26,340,000
North viaduct approach	8,200,000
Total	74,000,000
Estimated cost of superstructure	$3,514,000

This is about 4¾ cts. per lb. It would appear from one of the estimates made by another competitor that custom's duty of 1 ct. per lb. of steel ready for erection would be required.

A suspension bridge design was submitted by Mr. C. C. Wentworth, M. Am. Soc. C. E. It was to be a stiffened suspension bridge of 1,300 ft. span, with two 500 ft. side spans supported from the cables, giving a total length of 2,300 ft. There were to be 4 cables, each of 17½ ins. diameter. The two stiffening trusses were to be 52 ft. apart on the clear, leaving the roadway for the railway and electric lines. The carriageways and sidewalks were to be on brackets outside the trusses.

The estimated cost was as follows:

11,000,000 lbs. riveted steel center span, at 4.25 cts.	$ 467,500
20,000,000 lbs. steel in towers, side spans and anchorage, at 3½ cts.	700,000
30,000,000 lbs. steel in viaduct spans and towers, at 3 cts	900,000
8,000,000 lbs. wire in cables ,at 6 cts.	480,000
Copper covering on cables	20,000
Timber floors and ties	81,000
600 tons steel rails	18,000
Hand railing	25,000
60,000 cu. yds. anchorage masonry	360,000
Total for superstructure and anchorage	$3,051,500

It will be noted that if the same unit prices for steel had been assumed in both styles of bridge, the cost would have been more nearly equal, although about 7 per cent less for the suspension bridge.

Cost of the Brooklyn Suspension Bridge.—The Brooklyn Bridge across East River, New York City, was begun in 1870 and finished in 1883. Work was suspended at times due to lack of funds, so that the actual building required only 10 of the 13 years.

The roadway is 86 ft. wide, divided into five sections, two outside for vehicles and trolley cars, two inner for electric trains, and the middle one (12 ft.) for pedestrians. Height of bridge above high water in center, 135 ft.; height of masonry towers above high water, 272 ft. The Manhattan tower contains 46,945 cu. yds. of masonry. The Brooklyn tower contains 38,214 cu. yds. The depth of the Manhattan tower foundation below high water is 78 ft. The depth of the Brooklyn tower foundation below high water is 45 ft. Dimensions of towers at high water line, 59 x 140 ft.

The cost of the bridge and approaches was $9,000,000, or about $1,500 per lin. ft., or a little more than $17 per sq. ft. The cost of real estate and terminals was about $6,000,000 additional.

Comparative data as to the Brooklyn and Williamsburg bridges are given below.

The weight of the 1,545 ft. of main span of Brooklyn bridge between end suspenders is as follows:

	Lbs.
Cables	3,226,000
Suspended superstructure (steel work)	5,930,000
Timber flooring, track, etc.	2,380,000
Hauling, electric feeder, cables and line sleeves	220,000
Pneumatic tubes	262,000
Suspenders and connections	356,000
Over-floor stays (vertical loads)	386,000
Total fixed load on main span	12,760,000

Cost of the Williamsburg Suspension Bridge.—The Williamsburg bridge, across East River, at Delancy St., New York City, is the longest suspension bridge in the world, and its main span is exceeded only by the Forth cantilever bridge in Scotland. It was begun in 1896 and finished in 1903. The roadway is double deck, distributed as follows:

2 footwalks, each 10½ ft.	21 ft.
2 bicycle paths, each 7 ft.	14 ft.
2 elevated railway tracks	22 ft.
4 trolley tracks	40 ft.
2 roadways	40 ft.
Equivalent width single-deck bridge	137 ft.

The width of the main span is 118 ft. over all.

The comparative dimensions of the Williamsburg bridge and the Brooklyn bridge are given in Table II.

Table II—Comparative Dimensions of Williamsburg and Brooklyn Bridges, New York City.

	Bridges.	
Length:	Brooklyn.	Williamsburg.
Main span C. to C. of towers	1,595′ 6″	1,600′ 0″
Land spans, tower—anchorage	930′ 0″	596′ 6″
Brooklyn approach	971′ 0″	1,865′ 0″
Manhattan approach	1,562′ 6″	2,606′ 2″
Total of carriage way	5,989′ 0″	7,264′ 2″
Height:		
Clear, above M. H. W. at center	135′ 0″	140′ 4¾″
Same, 200′ each side of center	....	135′ 0″
Above M. H. W. to center of cable at tower	272′ 0″	332′ 8½″
Above M. H. W. to roadway in center of span	138′ 3″	145′ 5½″
Same, at center of tower	119′ 3″	125′ 7¾″
Of tower above roadway	159′ 0″	210′ 0″
Width of bridge	85′ 0″	118′ 0″
Grade of roadway in 100 ft.	3′ 3″	3′ 0″
Max. grade of roadway in 100 ft.	3′ 9″	3′ 4½″
Foundation below M. H. W.:		
Brooklyn	45′ 0″ S. 91.9′	N. 107.5′
Manhattan	78′ 0″ S. 66.0′	N. 55.0′

Size of Caissons:		
Brooklyn	168 x 102′	(2) 63 x 79′
Manhattan	172 x 102′	(2) 60 x 76′
Size of anchorages:		
At base—Brooklyn	129 x 119′	177 x 158′
At base—Manhattan	129 x 119′	173′ 4½″ x 151′ 9″
At top	117 x 104′	149′ x 127′ 5″
Diameter of cables	15⅝	18¾
Number wires in each cable	5,296	7,700
Length of wire weighing 1 lb	12′	10′ 3″
Weight of one cable per lin. ft	500 lbs.	770 lbs.
Total miles of wire in 4 cables	14,361	17,432
Versine at mean temperature	128′	178′
Ultimate strength each cable, tons	12,200	24,500
Permanent weight suspended:		
From main span cables, tons	6,780	13,740
From shore span cables, tons	7,900	0

The main towers of Williamsburg Bridge are of steel, 310 ft. high from top of masonry to center of cable over the tower.

The quantities of the principal materials were as follows:

	Lbs.
2 towers	12,192,000
2 end spans	12,280,000
1 main suspended span	15,544,000
Cables and suspenders	10,000,000
Brooklyn viaduct approach	12,170,000
New York viaduct approach	21,100,000
In anchorages	6,200,000
Total	89,486,000
Concrete, cu. yds	60,000
Stone masonry, cu. yds	130,000
Excavation, cu. yds	125,000
Timber, ft. B. M.	8,000,000

The cost of the bridge was $11,000,000 (exclusive of land), and some of the items were as follows:

Anchorages, Brooklyn side	$ 771,778
Anchorages, Manhattan side	797,770
Tower foundation, Brooklyn	485,082
Tower foundation, Manhattan	373,462
Suspended span	1,123,400
Brooklyn viaduct approach	947,000
New York viaduct approach	1,464,000
Cables	1,398,000

Cost of Two Pneumatic Foundations for the Williamsburg Bridge.—The following data were given by Mr. Francis L. Pruyn in *Engineering-Contracting,* Aug. 8, Aug. 15, and Aug. 22, 1906:

The work here described consisted of sinking two large caissons, 63 x 79 ft. in size on the Brooklyn side of the Williamsburg Bridge to bed rock, in one case 86 ft. and in the other 110 ft. below mean high water, filling same with concrete and building masonry piers upon this foundation inside of coffer dams up to elevation plus 23 ft. above M. H. W. All work was done by contract during the years 1897 to 1899.

The caissons were constructed of yellow pine timber at the site of the work, launched, floated into place and sunk to the river

bottom, which was about 55 ft. below M. H. W., by filling them with concrete.

Compressed air was then turned on, and the caissons were sunk to bed rock. The material encountered, consisting of river mud, sand, clay and rock, was excavated either by means of Moran patent material locks or by wet blow out; finally the working chamber was filled with concrete. While the caissons were being sunk, the coffer dams, which were attached to the caissons, were added in order to keep their tops above water, and inside of these coffer dams the masonry piers were built. During the sinking process the masonry was built only in sufficient quantity to give the weight necessary for sinking the caissons. After the caissons were sealed and the air taken off, the shafting and piping were removed, the spaces occupied by them filled with concrete, and the pier carried up to its final elevation. The coffer dams were then removed.

The costs recorded were kept by daily engineer's force account, and are as accurate as is possible by that method. The plant charges were obtained by a careful inventory, to which prevailing prices were affixed. Depreciation was charged off at about 40 per cent, which is perhaps 10 per cent too low. The general expense was 10 per cent of the total cost of materials and labor and included bond, interest on money invested, office and dock rentals, superintendent and field office salaries, watching, etc. No allowance was made for maintenance of main office.

Cost of Two Caissons.—The caissons were 63 x 79 ft. in size; the south one was 39 ft. high and the north 53 ft. high. They were built one at a time, directly at the site of the work; the launching ways extending back from the bulkhead line. A floating pile driver fitted with a 70-ft. boom was used to build them. This served its purpose well, as the heel of the boom could be raised as the caissons were built up. When the caisson walls were 20 ft. high the caissons were launched and towed to site, where they were completed. The framing and building was done under the direction of a very capable foreman, who obtained good and rapid work from his carpenters. All framing was done by hand; a steam auger was used where practical for boring bolt holes, and a steam hammer was used part of the time for driving drift bolts. The sides and roof of caisson were built up of two courses of 12 x 12 timber, the outside was sheathed with two courses of 3-in. tongue and groove plank. There was also two courses of 3-in. plank in the roof. Above the caisson roof a cribwork of 12 x 12-in. timbers divided the space inside the walls into pockets 6 ft. square. This cribwork was trussed by means of 3-in. plank spiked on; it served to keep the weight of concrete and pier masonry off the roof.

The working chamber, which was 7 ft. high, was divided by suitable bulkheads. In order to secure air tightness the seams were calked with two strands of oakum well forced in. The chamber was then lined with 3-in. plank, the joints of which, as well as the spikes used in fastening same, were also treated with two strands of oakum and afterwards painted with white lead.

The labor prices paid per 10-hour day were as follows:

Foreman	$5.00
Sub-foreman	3.00
Carpenter	3.00
"	2.50
Riggers	2.00
Hoist Runners	2.50
Steam Fitters	3.00
" "	2.50
Blacksmith and Helpers	4.00
Laborers	1.50
Calkers	3.25

It will be noted that these rates are from 20 to 50 per cent lower than the present rates, which are now based on an 8-hour day for municipal work.

The south caisson was built first, and the difference in cost between it and the north caisson was brought about by the better organization on the second caisson, and by the larger quantity of the cheaper kind of framing in the cobwork and walls above the roof. The cost of material and labor is given in Table III.

Figures 1 and 2 show the general construction of the caissons, method of framing, etc. [The figures are given in *Engineering-Contracting,* but omitted here on account of their size.] It is of interest to note the increase in prices of yellow pine timber and other materials that had taken place since this work was done.

The South Caisson was begun Aug. 13th, launched with walls 20 ft. high Oct. 19th and finished to 39 ft. high Nov. 17th.

The North Caisson was begun Oct. 20th, launched Nov. 30th and finished to 53 ft. high Feb. 8th, 1898.

Launching Ways.—The caisson as launched 20 ft. high weighed 954 tons and drew 11½ ft. of water. The ways, four in number, were placed one under each outside wall and one under each bulk head. They consisted of two 12 x 12 timbers bolted side by side, sliding on two similar timbers fastened to the caisson. Three-inch plank were bolted to the outside of the ways to serve as guides. They were sloped 1¼ ins. to the foot, and extended 5 ft. below M. H. W. The pressure on the ways was 255 lbs. per sq. in. and they were lubricated with a mixture of tallow and graphite.

Cost of Two Coffer Dams.—Coffer dams 50 ft. high were attached to the caissons in order to allow sinking to proceed independently of, and without waiting for, the construction of the masonry, and also to keep the pressure on the cutting edge of the caisson under perfect control. The coffer dams were attached to the caissons by removable bolts, and built up in three sections 17 ft. high. The thickness of the walls diminished from 12 ins. on the bottom section to 6 ins. on the top and the interior horizontal bracing provided for 13 ft. pockets for setting the masonry. The bracing was trussed with 3-in. plank in the same manner as the caissons, but so arranged that it could be removed as the pier masonry was built up.

The coffer dams were built at night to avoid interference with other work. The cost of the material and labor is given in Table IV.

TABLE III.—TOTAL COST OF TIMBER WORK ON CAISSONS.

Materials.	South Caisson. Quantity.		Rate.	Amount.	North Caisson. Quantity.		Rate.	Amount.
Timber: Yellow pine	765	M	$18.50	$14,140.00	980	M	$18.50	$18,120.00
Iron: Bolts, rods, etc	76.6	tons	35.00	2,679.00	90.5	tons	35.00	3,168.00
Oakum	55	bales	2.50	137.00	75	bales	2.50	187.00
Pitch	3	bbls.	4.00	12.00	3	bbls.	4.00	12.00
Paint	1,000	lbs.	0.06	60.00	1,000	lbs.	0.06	60.00
Roofing tar	18	bbls.	2.25	41.00	19	bbls.	2.25	43.00
Total materials	765	M	$22.30	$17,069.00	980	M	$22.00	$21,590.00
Labor.								
Handling, framing and building	765	M	$13.60	$10,372.00	980	M	$12.50	$12,277.00
Caulking	"		.90	690.00	"		.71	695.00
Launching	"		.27	211.00	"		.40	390.00
Total labor	765	M	$14.77	$11,273.00	980	M	$13.61	$13,362.00
Plant charges	"		1.64	1,250.00	"		1.42	1,386.00
Plant labor charges	"		1.86	1,425.00	"		1.26	1,231.00
	765	M	$ 3.50	$ 2,675.00	980	M	$ 2.68	$ 2,617.00
Total				$31,017.00				$37,569.00
Gen. expenses, superintendent, etc., 10%	765	M	$ 4.00	$ 3,102.00	980	M	$ 3.83	$ 3,757.00
Grand total	765	M	$44.57	$34,119.00	980	M	$42.12	$41,326.00

TABLE IV.—COST OF COFFER DAMS.

Materials.	South Coffer Dam. Quantity.		Rate.	Amount.	North Coffer Dam. Quantity.		Rate.	Amount.
Timbers: Yellow pine	309	M	$19.00	$ 5,870.00	228	M	$19.00	$ 4,335.00
Iron: Rods, bolts, etc	24½	tons	35.00	858.00	23½	tons	35.00	823.00
Oakum	48	bales	2.50	120.00	48	bales	2.50	120.00
Total	309	M	$22.20	$ 6,848.00	228	M	$23.10	$ 5,278.00
Labor.								
Handling, building and framing	309	M	$15.80	$ 4,867.00	228	M	$16.30	$ 3,704.00
Caulking	"		1.49	461.00	"		6.41	1,461.00
Removing braces	"		2.18	673.00	"		1.78	394.00
Removing coffer dam	"		1.17	363.00	"		.96	220.00
Total labor	309	M	$20.64	$ 6,364.00	208	M	$25.40	$ 5,779.00
Plant charges			1.48	458.00			1.54	351.00
Total material and labor	309	M	$44.32	$13,670.00	208	M	$50.04	$11,408.00
General expenses, 10%			4.43	1,367.00			5.00	1,141.00
Grand total	309	M	$48.75	$15,037.00	208	M	$55.04	$12,549.00

It was found after the south coffer dam was built that the walls were unnecessarily heavy. This was corrected in building the north coffer dam, which accounts for its increased cost per M. ft. B. M.

Figure 3 [not reproduced here] shows the general design and details of the coffer dam construction, as well as method of temporary attachment to caissons.

Concrete in Caissons.—After each caisson was built it was towed to its proper site, where it was held in place by temporary pile dock built completely around it. On these docks the concrete was placed; a 2 cu. yd. cubical mixer of the usual pattern being used for mixing. The concrete materials, consisting of sand, stone and cement were handled direct from barges alongside, into the mixer. The concrete was placed by a derrick located in the center of the caisson, which was a bad feature as the caisson was usually out of level and considerable difficulty was experienced in swinging the derrick. On the south caisson ¾ cu. yd. bottom dump buckets were used in placing the concrete, on the north caisson the size of these was increased to 1½ cu. yd. which reduced the cost of placing 15 cts. per cu. yd. There were placed in the south caisson 3,827 cu. yds. in 32 days of actual working time—120 cu. yds. per day of 10 hrs. The gross time was 2 months. On the north caisson 5,693 cu. yds. were placed in 46 days worked—124 cu. yds. per day. The gross time was 4 months. See Table V.

The rates of labor were as follows per 10-hour day:

Foreman	$5.00
Assistant foreman	2.50
Hoisters	2.50
Fireman	1.60
Laborer	1.50

Proportions concrete were 1 : 2.5 : 6.

The low price of sand in the north caisson was brought about by the finding of good building sand in the excavation for the anchorage, which work was done by the same contractor.

When the caissons had been sealed the iron material shafts were removed. This left holes 5 ft. x 6 ft. extending from the roof of the caisson up to M. H. W. which were filled with concrete. These shaft holes were 80 ft. deep on the south caisson and 100 ft. deep on the north caisson. They were partially filled with water and the concrete had to be placed with considerable care. Wooden chutes were used on the south caisson; they rested on the caisson roof, were filled with concrete and then raised allowing concrete to flow out at the bottom. The shaft holes were too deep on the north caisson for chutes and 20 cu. ft. bottom dump buckets were used. They had to be lowered to bottom of shaft each trip before dumping, a slow operation, which greatly added to the cost. Proportion for concrete 1 : 2.5 : 6. See Table VI.

The proportion for concrete in working chamber was the same as for all other concrete. The specifications called for 6 ins. of mortar, of 1 part of cement to 2½ parts of sand and between the concrete and all bearing areas; that is, under the cutting edge and

TABLE V.—COST OF CONCRETING CAISSONS ABOVE ROOF.

Materials.	South Caisson (3,827 cu. yds.) Quantity.	Rate.	Amount.	North Caisson (5,693 cu. yds.) Quantity.	Rate.	Amount.
Cement	4,480 bbls.	$1.57	$ 7,034.00	6,707½ bbls.	$1.57	$10,531.00
Sand	1,288 cu. yds.	.60	773.00	2,133 cu. yds.	.40	845.00
Broken stone	3,421 cu. yds.	1.50	5,132.00	4,938 cu. yds.	1.10	5,432.00
Water			36.00			51.00
Total	3,827 cu. yds.	$3.39	$12,975.00	5,692 cu. yds.	$2.96	$16,859.00
Labor.						
Mixing and placing	3,827 cu. yds.	$0.90	$ 3,432.00	5,692 cu. yds.	$0.73	$ 4,159.00
Plant charges			2,280.00			2,952.00
Plant labor			742.00			517.00
Total plant	3.827 cu. yds.	$0.79	$ 3,022.00	5,692 cu. yds.	$0.61	$ 3,469.00
Total cost	3.827 cu. yds.	$5.08	$19,429.00	5,692 cu. yds.	$4.30	$24,487.00
General expenses, 10%	3.827 cu. yds.	.51	1,943.00	5,692 cu. yds.	.43	2,448.00
Grand total	3,827 cu. yds.	$5.59	$21,372.00	5,692 cu. yds.	$4.73	$26,935.00

directly under the roof of the working chamber. The concrete was mixed in the cubical mixer and dumped on the bottom door of the material lock, the top door of the lock was then closed, the bottom door opened and the concrete fell through the shaft to the working chamber. It was then shoveled by the sand hogs into place. A 6-in. space was left below all bearing surfaces into which damp mortar was tightly rammed. Concreting the south caisson took 10¼ working days of 24 hours, the gangs working night and day in twelve 2-hour shifts; 1,566 cu. yds. of concrete and mortar were placed, or at the rate of 140 cu. yds. per 24 hours. The gross time including Sundays was 14½ days. The sand hogs worked in shifts of 2 hours each and received $3.50 for the two hours work. The twelve foremen received $1 more; the average gang consisted of 12 sand hogs.

On the north caisson the organization was much better, owing to the experience gained on the first caisson; and in spite of the fact that the sand hogs, on account of the increased depth, received $4.00 for 1½ hours work, or an increase of $22.00 per man per 24 hrs. over that on the south caisson, the work was done for less money. There were placed 1,566 cu. yds. of concrete in 7 working days of 24 hrs., or at the rate of 224 cu. yds. per day. The gross time was 11½ days including Sundays. The average number of men in the sand hog gangs was 18, with one foreman, who received $5 for 1¼ hours work. See Table VII.

Cost of Sinking Caissons.—The cost of sinking caissons has been subdivided according to the materials encountered and also with reference to the depth of cutting edge, as the price paid the pressure men varies with the depth. The following were the union rates paid to "sand dogs," or workmen:

From 0 to 50 ft. below M. H. W.	$2.50	for 8 hours
55 to 70 ft. below M. H. W.	2.75	for 6 hours
70 to 80 ft. below M. H. W.	3.00	for 4 hours
80 to 90 ft. below M. H. W.	3.25	for 2 hours
90 to 100 ft. below M. H. W.	3.50	for 1 hour
100 to 110 ft. below M. H. W.	3.75	for 1 hour

When connecting chamber, the price was increased 25 cts. per shift.

Compressor engineers received $3.60 per day, foremen $2.60 and coal passers $2. The superintendent in charge of the pneumatic work received $6 per day and his night assistants $5.

The present "sand hog" rates have increased 20% over these figures.

The air plant consisted of three 100-hp. vertical boilers, 3 Laidlaw-Dunn-Gordon Duplex Compressors, 16-in. steam and 18-in. air cylinders with 18-in. stroke, and two high pressure force pumps. One 6-in. pipe supplied air to the caissons, and one 5-in. pipe supplied the water. There were also three 4-in. blowout pipes, six 3-ft. material shafts and one 6-ft. man shaft with elevator. Docks were built around the caissons to hold them in position while sinking; on one of these the compressor plant was located. The clay encountered was a very hard stratified material and difficult

TABLE VI.—COST OF CONCRETE IN SHAFT HOLES.

Materials.	South Caisson. Quantity.	Rate.	Amount.	North Caisson. Quantity.	Rate.	Amount.
Concrete	612½ bbls.	$1.57	$ 962.00	614½ bbls.	$1.57	$ 965.00
Sand	193 cu. yds.	.40	77.00	204 cu. yds.	.40	82.00
Stone	493 cu. yds.	1.10	542.00	521 cu. yds.	1.10	574.00
Total	541 cu. yds.	$2.92	$1,581.00	576 cu. yds.	$2.82	$1,621.00
Labor.						
Handling, mixing and placing	541 cu. yds.	.96	519.00	576 cu. yds.	1.70	982.00
Plant charges, etc.	"	1.06	576.00	"	1.36	795.00
Total	541 cu. yds.	$4.94	$2,676.00	576 cu. yds.	$5.88	$3,398.00
General expenses, 10%	541 cu. yds.	.49	267.00	576 cu. yds.	.59	339.00
Grand total	541 cu. yds.	$5.43	$2,943.00	576 cu. yds.	$6.47	$3,737.00

TABLE VII.—COST OF CONCRETE IN WORKING CHAMBERS.

Materials.	South Caisson (1,435 cu. yds.). Quantity.	Rate.	Amount.	North Caisson (1,566 cu. yds.). Quantity.	Rate.	Amount.
Cement for concrete	1,666 bbls.	$ 1.57	$ 2,615.00	1,559 bbls.	$1.51	$ 2,446.00
Cement for mortar	459 bbls.	1.57	720.00	442 bbls.	1.51	694.00
Sand for both	670 cu. yds.	.40	268.00	630 cu. yds.	.40	252.00
Broken stone	1,181 cu. yds.	1.10	1,299.00	1,380 cu. yds.	1.10	1,518.00
Total materials	1,435 cu. yds.	$ 3.42	$ 4,902.00	1,566 cu. yds.	$3.14	$ 4,910.00
Labor.						
Top labor, mixing and placing	"	$ 1.09	$ 1,575.00	"	$ 0.78	$ 1,198.00
Pneumatic labor	"	4.93	7,117.00	"	4.91	7,694.00
Compressor house labor	"	.19	275.00	"	.11	180.00
Total labor	1,435 cu. yds.	$ 6.21	$ 8,967.00	1,566 cu. yds.	$ 5.80	$9,072.00
Plant.						
Coal at $2.40 per ton	"	.10	140.00	"	.06	$ 87.00
Concrete plant	"	.79	1,145.00	"	.86	1,352.00
Pneumatic plant	"	1.05	1,522.00	"	.81	1,272.00
Total plant	1,435 cu. yds.	$ 1.94	$ 2,807.00	1,566 cu. yds.	$ 1.73	$ 2,711.00
Totals	1,435 cu. yds.	$11.57	$16,676.00	1,566 cu. yds.	$10.67	$16,693.00
General expenses, 10%	"	1.16	1,667.00	"	1.06	1,669.00
Grand total	1,435 cu. yds.	$12.73	$18,343.00	1,566 cu. yds.	$11.73	$18,362.00

to excavate. The rock was the ordinary New York gneiss and was drilled by hand. The cost of plant was estimated from inventory taken, as the prices paid for it were not available. The supplies also had to be estimated, and the charge for them, as well as the plant are, probably 10 to 15% low.

Cost of Sinking South Caisson—

(1) Sand with boulders, 3 gangs per day at 8 hours each. Elevation—53.5 ft. to —56.25 ft.

Labor sinking	$1,583.00
Temporary docks	88.00
Plant	867.00
Supplies	489.00
Total	$3,027.00
General expenses, 10%	303.00
Total, 509 cu. yds., at $6.55	$3,330.00

(2) Sand with boulders, 4 gangs per day at 6 hours each. Elevation —56.25 ft. to —66.7 ft.

Labor sinking	$ 6,828.00
Temporary docks	236.00
Plant	2,310.00
Supplies	1,307.00
Total	$10,681.00
General expenses, 10%	1,068.00
Total, 1,929 cu. yds., at $6.10	$11,749.00

(3) Clay and Stratified Clay. Elevation —66.7 to —71.25 ft., 4 gangs per day at 6 hours each.

Labor sinking	$3,763.00
Temporary docks	110.00
Plant	1,083.00
Supplies	613.00
Total	$5,569.00
General expenses, 10%	557.00
Total, 839 cu. yds., at $7.31	$6,126.00

(4) Stratified Clay, 6 gangs per day at 4 hours each. Elevation —71.25 to —80.19 ft.

Labor sinking	$ 9,462.00
Temporary docks	191.00
Plant	1,876.00
Supplies	1,063.00
Total	$12,592.00
General expenses, 10%	1,259.00
Total, 1,648 cu. yds., at $8.42	$13,851.00

(5) Sound Gneiss Rock, 6 gangs per day at 4 hours each. Elevation —80.19 to —81.25 ft.

Labor sinking	$ 4,595.00
Temporary docks	96.00
Plant	937.00
Supplies	530.00
Explosives	81.00
Total	$ 6,239.00
General expenses, 10%	624.00
Total, 195 cu. yds., at $35.20	$ 6,863.00

(6) Stratified Clay—Stripping Rock. Elevation —81.25 to —83.3 ft., 12 gangs per day at 7 hours each.

Labor sinking	$ 8,158.00
Temporary docks	102.00
Plant	1,010.00
Supplies	42.00
Total	$ 9,312.00
General expenses, 10%	931.00
Total, 380½ cu. yds., at $26.90	$10,243.00

(7) Work Incidental to sinking South Caisson.

Recaulking chamber	$ 904.00
Blocking in chamber	1,228.00
Total	$2,132.00

Cost of Sinking North Caisson—

(1) Material—Mud, Sand and Gravel. Elevation —51.7 to —56.8 ft., 3 gangs per day at 8 hours each.

Labor sinking	$2,351.00
Temporary docks	80.00
Plant	854.00
Supplies	383.00
Total	$3,668.00
General expenses, 10%	367.00
Total, 1,714 cu. yds., at $2.35	$4,035.00

(2) Material—Fine Sand. Elevation —68.6 to —73.3 ft., 4 gangs per day at 6 hours each.

Labor sinking	$3,133.00
Temporary docks	88.00
Plant	931.00
Supplies	413.00
Total	$4,565.00
General expenses, 10%	456.00
Total, 2,175 cu. yds., at $2.31	$5,021.00

(3) **Material—Clay and Stratified Clay. Elevation—68.6 to —73.3 ft., 4 gangs per day at 6 hours each.**

Labor sinking	$2,230.00
Temporary docks	81.00
Plant	853.00
Supplies	378.00
Total	$3,542.00
General expenses, 10%	354.00
Total, 866 cu. yds., at $4.50	$3,896.00

(4) **Material—Stratified Clay. Elevation—73.3 to —81.4 ft., 6 gangs per day at 4 hours each.**

Labor sinking	$7,500.00
Temporary docks	140.00
Plant	1,480.00
Supplies	655.00
Total	$9,775.00
General expenses, 10%	977.00
Total, 1,493 cu. yds. at $7.20	$10,752.00

(5) **Material—Stratified Clay. Elevation—81.4 to —89.8 ft., 12 gangs per day at 2 hours each.**

Labor sinking	$11,130.00
Temporary docks	154.00
Plant	1,630.00
Supplies	724.00
Total	$13,638.00
General expenses, 10%	1,364.00
Total, 1,621 cu. yds. at $9.25	$15,002.00

(6) **Material—Sound Gneiss Rock "Benching." Elevation—83.5 to —91.25 ft., 12 gangs per day at 2 hours each.**

Labor	$4,753.00
Temporary docks	74.00
Plant	776.00
Supplies	345.00
Explosives	35.00
Total	$5,983.00
General expenses, 10%	598.00
Total, 84 cu. yds. at $78.40	$6,581.00

(7) **Material—Stratified Clay. Elevation—91.25 to —95.00 ft., 14 gangs per day at 1½ hours each.**

Labor	$9,770.00
Temporary docks	88.00
Plant	932.00
Supplies	414.00
Total	$11,204.00
General expenses	1,120.00
Total, 702 cu. yds. at $17.55	$12,324.00

(8) Materials—Sound Gneiss Rock Benching. Elevation—91.25 to —95 ft., 14 gangs per day at 1½ hours each.

Labor	$13,303.00
Temporary docks	101.00
Plant	1,165.00
Supplies	516.00
Explosives	105.00
Total	$15,190.00
General expenses	1,519.00
Total, 2,534 cu. yds. at $65.80 per cu. yd.	$16,709.00

(9) Materials—Stratified Clay, Stripping Rock. Elevation—95 to —110 ft., 14 gangs per day at ½ hours each.

Labor	$9,232.00
Temporary docks	66.00
Plant	698.00
Supplies	310.00
Total	$10,306.00
General expenses, 10%	1,031.00
Total, 453 cu. yds. at $25.00	$11,337.00
(10) Recalking chamber cost	$ 715.00

The cost of stripping and cleaning up rock is excessively high, but this work is necessarily slow, the quantity of actual excavation small and the labor rate of from $1.75 to $1.87 per hour is about 10 times that for similar work above ground. The fixed plant and overhead charges are likewise heavy.

The same explanation applies to the high rock excavation cost, besides which very small charges of powder had to be used owing to danger of injuring the caisson, as well as the danger of blowouts under the cutting edge. Therefore holes had to be drilled close together.

All drilling was done by hand; power drills would have greatly reduced the cost. The delay caused by blasting is expensive in this class of work; the whole gang has to go up in the airlock at almost every shot.

Cost of Pier Masonry.—The masonry was begun at the elevation of the top of the caissons and carried up to elevation 24 ft. above M. H. W. in courses varying from 2 ft. 6 ins. in thickness at the bottom to 2 ft. at the top. The pier was built of limestone up to 4 ft. below M. L. W., above which the facing was of rock faced granite with the backing of limestone. The two top courses, as well as the pedestals, were built entirely of granite, all exposed surfaces of which were 6-cut. All other face stones, whether of limestone or granite, were of rock faced with ½-in. beds and joints. The backing was built of roughly squared stones with ½-in. beds, and 3-in. joints. Spalls were used in filling the joints. See Table VIII.

Cramps and dowels were used in the two top courses of granite.

The plant consisted of derricks surrounding each pier. The limestone was unloaded direct from barges. Two extra barges were kept continuously at the site for storage purposes. The

TABLE VIII.—COST OF PIER MASONRY.

Materials.	South Pier. Quantity.		(6,883 cu. yds.) Rate.	Amount.	North Pier. Quantity.		(6,898 cu. yds.) Rate.	Amount.
Limestone facing	1,190	cu. yds.	$ 8.55	$10,187.00	1,119.5	cu. yds.	$ 6.50	$ 7,280.00
Limestone backing	3,809	cu. yds.	6.97	26,580.00	3,893	cu. yds.	$5.90	22,960.00
Granite facing	657.7	cu. yds.	15.89	10,430.00	657.7	cu. yds.	15.89	10,430.00
Granite backing	160	cu. yds.	23.64	3,786.00	160	cu. yds.	23.64	3,786.00
Granite coping	471.6	cu. yds.	23.64	11,150.00	471.6	cu. yds.	23.64	11,150.00
Cement	2,783	bbls.	1.57	4,349.00	2,915	cu. yds.	1.57	4,550.00
Sand	850	cu. ft.	.40	340.00	941	cu. yds.	.40	377.00
Water	5	M cu. ft.	1.00	5.00				5.00
Spalls				200.00				200.00
Dowels	1,080	lbs.	.04	43.00	1,080	lbs.	.04	43.00
Total	6,883	cu. yds.	$ 9.75	$67,070.00	6,898	cu. yds.	$ 8.80	$60,781.00
Labor setting	6,883	cu. yds.	$ 1.26	$ 8,706.00	6.898	cu. yds.	$ 1.08	$ 7,453.00
Plant.								
Coal	225	tons	2.40	540.00	145	tons	$ 2.40	$ 348.00
Water for boilers				73.00				47.00
Plant charges				6,400.00				4,969.00
Total plant	6,883	cu. yds.	$ 1.02	$ 7,013.00	6,898	cu. yds.	$ 0.78	$ 5,364.00
Grand total	6,883	cu. yds.	$12.03	$82,789.00	6.898	cu. yds.	$10.66	$73,598.00
General expenses at 10%	6,883	cu. yds.	1.20	8,279.00	6.898	cu. yds.	1.07	7,360.00
Total	6,883	cu. yds.	$13.23	$91,068.00	6,898	cu. yds.	$11.73	$80,958.00

granite was unloaded, cut and stored on adjacent docks rented for the purpose. The mortar was mixed by the concrete plant in proportions, 1 of cement to 2½ of sand, and handled in buckets by the derricks.

The interference on this class of work is great, and the organization that can be attained where masonry work alone is carried on, is not possible. The coffer-dam braces interfere with the progress, as well as the fact that the quantity of masonry which can be set while the caisson is being sunk depends on the weight required on the cutting edge and not on the efficiency of the masonry gang. The first pier was built in 122 gang days, or at the rate of 56 cu. yds. per day; the second one was completed in 77 gang days, or at the rate of 90 cu. yds. per day. This increased performance was made possible by the more rapid sinking of the second caisson as well as by better organization.

In the total masonry for both piers up to the coping courses the voids were—in backing 12%, in face stone 6%. In the coping courses the voids were 3½%.

The labor rates were as follows per 10-hour day:

	Per day.
Foreman	$5.00
Asistant foreman	4.50
Masons	3.20
Stone cutters	3.00
Hoister runners	2.75
Laborers	1.50

Cost of Erecting the Brooklyn Towers and End Spans of the Williamsburg Bridge, New York City.—The following data were given by Mr. Francis L. Pruyn in *Engineering-Contracting*, Oct. 24, 1906:

The work consisted of the erection complete in place, of a steel tower 310 ft. high on the tower foundations, the erection of truss 596 ft. long, the connecting of the same with the cable anchorage, and the construction of an intermediate tower about 100 ft. high supporting the center of the end span.

Main Tower.—The main tower consisted of eight heavy columns braced laterally in all directions. At the floor level they were provided with a system of heavy girders to support the end of the land truss as well as the end of the suspended structure, the main span of the bridge. At the top of the tower another system of heavy girders was provided on which rested saddles for the cables of the suspended structure.

The actual erection of falsework for the main tower began in January, 1900, and the erection and painting of steel work was finished in November, 1901. The falsework consisted of a heavy flooring resting on seven 60-ft. trusses extending between the masonry piers. On the floor was placed the boilers and engines which were used for raising all steel work for the tower. The main falsework, consisting of a heavily braced timber tower, was put up in three sections. The first section extended to the roadway level, and was about 100 ft. high. On top of this

were erected two heavy A frame derricks for hoisting the steel and two smaller derricks for handling the lighter parts. The steel work was then erected up to the roadway level. On top of the roadway the second section of timber tower was erected about 107 ft. high, the derricks were transferred to its top. and the steel work erected as far as possible. The first section of falsework tower below the roadway was then wrecked and re-erected on top of the second section, the derricks again transferred, and the erection of tower completed. After steel tower was erected a heavy timber gallows frame was built on top of it for hoisting the cable saddles into place.

In the erection of falsework, steel work, etc., the Bridgemen's Union was employed. The rate of wages for its members was $3.20 for eight hours at the start of the work; later the rate was increased to $3.76 per day. The general rate of wages for the erection of falsework for main towers for an eight-hour day was as follows:

Foremen	$5.00
Sub-Foremen	3.50
Carpenters and steel men	3.20
Hoisters	3.50
Laborers	2.00

The cost of erecting the falsework for the main towers is shown in Table IX.

TABLE IX.—COST OF ERECTING FALSE WORK FOR MAIN TOWERS.

Cost of First Section, Including Trusses Between Piers, Floor, Engine House and A Frame Derricks.

	Quantity.		Rate.	Amount.
Yellow pine timber	74.6	M. ft., B. M.	$24.45	$1.823.00
Iron and steel	42.4	Tons	77.00	3,261.00
Labor	74.6	M. ft., B. M.	53.00	3,959.00
Total			......	$9,043.00

Cost of Second Section of False Work and Raising Derricks on Top of Same.

	Quantity.		Rate.	Amount.
Yellow pine timber	42	M. ft., B. M.	$26.40	$1,110.00
Iron and steel	19.6	Tons	73.00	1,427.00
Labor	42	M. ft., B. M.	61.80	2,601.00
Total			......	$5,138.00

Cost of Third Section of False Work, Consisting of Wrecking First Section and Re-Erecting Same.

	Quantity.		Rate.	Amount.
Yellow pine timber	26.4	M. ft., B. M.	......	....
Iron and steel	11½	Tons	......	....
Labor	26.4	M. ft., B. M.	$77.50	$2,047.00
Total			......	$2,047.00

Cost of Gallows Frame Erected on Top of Tower.

	Quantity.	Rate.	Amount.
Yellow pine timber........	8.1 M. ft. B. M.	$15.00	$122.00
Iron and steel............	½ Ton	80.00	40.00
Labor	8.1 M. ft., B. M.	104.00	943.00
Total	....	......	$1,105.00

Cost of Wrecking Second and Third Sections of False Work as Well as Staging Between Masonry Piers.

	Quantity.	Rate.	Amount.
Yellow pine timber........	....	......	....
Iron and steel............	....	......	....
Labor	124.7 M. ft., B. M.	$26.65	$3,325.00
Total	....	......	$3,325.00

Total Cost of Erecting and Wrecking False Work, Complete.

	Quantity.	Rate.	Amount.
Yellow pine timber........	124.7 M. ft., B. M.	$24.50	$3,055.00
Iron and steel............	62.5 Tons	75.80	4,728.00
Labor	151.1 M. ft., B. M.	85.25	12,875.00
Plant	....	......	1,314.00
Plant, labor............	....	......	1,285.00
General expenses, 10%....	....	......	2,326.00
Total	....	......	$25,583.00

The total weight of the tower was 3,071 tons, therefore the falsework cost $8.32 per ton. It should be noted that no salvage has been allowed on timber or iron.

False Work for End Span.—The false work for the end span consisted of a heavy timber structure about 575 ft. long and averaging about 90 ft. in height. The bents were made up of 12 x 12-in. yellow pine timber fastened together with iron fish plates and ¾-in. bolts and braced with 6-in. sway bracing. The portion from the main towers to the bulkhead, about 190 ft., was built on a pile trestle in 50 ft. of water. A 40-ft. truss spanned Kent Ave. A traveler was built on top of the false work by means of which the steel work was erected.

Cost of Pile Dock.—The pile dock was built in 50 ft. of water, where the current ran at times 6 miles an hour. The river bottom was hard and the piles did not penetrate over 10 ft. For these reasons it was built much more carefully than is customary with this class of temporary structures. The piles were of Norway pine, 70 ft. long with 18-in. butts. The capping was of 12 x 12-in. yellow pine timber carefully framed and heavily bolted. The whole was braced by 12 x 12-in. and 4 x 12-in. timber.

The labor rates for a 10-hour day were:

Foremen	$5.00
Dock builders	2.25
Hoisters	2.50

The dimensions of the trestle were 190 ft. x 89 ft., making a total of 16,900 sq. ft.

Driving 226 Bearing Piles.

	Per Pile.	Total.
Labor	$ 3.25	$ 735.00
Piles, at $18	18.00	4,068.00
Pile driver	1.21	275.00
Total, 226 piles, at	$22.46	$5,078.00

Driving Land Bent.

	Per Pile.	Total.
Labor	$ 7.57	$197.00
26 to 20 ft. piles	10.00	260.00
Pile driver	2.69	70.00
Total, 26 piles, at	$20.26	$527.00

Driving 36 (70 ft.) Spar Piles.

	Per Pile.	Total.
Labor	$ 5.36	$193.00
36 piles, at $18	18.00	576.00
Pile driver	2.22	80.00
Total, 36 piles, at	$25.58	$849.00

Driving 36 (60 ft.) Fender Piles.

	Per Pile.	Total.
Labor	$ 3.80	$137.00
36 piles	16.00	576.00
Pile driver	1.11	40.00
Total, 36 piles, at	$20.91	$773.00
Total cost of driving		$7,227.00

Cost of Framing and Bracing Pile Trestle.

Labor	$1,912.00
93 M. ft., B. M., Y. P. capping	2,568.00
19 tons iron	1,081.00
Pile driver	220.00
	$5,781.00

Erecting.

Total cost of pile dock	$13,008.00
Cost of wrecking	665.00
Grand total	$13,673.00
General expenses, at 10%	1,367.00
	$15,040.00

There were 16,900 sq. ft. of dock, which, therefore, cost 89 cts. per sq. ft.

False Work Trestle for End Span.—The false work for the cantilever span, which extended from the intermediate tower to the

anchorage, consists of 17 bents 20 ft. apart, and from 60 ft. to 90 ft. high and included the truss across Kent. Ave., which was made up of nine trusses 48 ft. long and 15 ft. deep. After the cantilever span was erected, seven bents were moved forward to serve as false work for the connecting span and the remainder of the steel work erected. The timber bents were erected stick by stick in place, and not, as is customary, by building on the ground and erecting the bent as a unit.

The steel work was erected by means of a traveler running on tracks on top of the false work. It was 45 ft. square by 47 ft. high, and was furnished with four 10-ton derricks, which were mounted on top of it. A 20-ton derrick was set up on the extreme end of the false work for raising the steel from the ground to cars on top of the false work. As in the case of the false work for the towers, all labor had to be furnished by the Bridgemen's Union.

Total Cost of Erecting 17 Bents and Moving Forward 7 Bents and Kent Ave. Truss.

Labor, building and wrecking 17 bents	$12,636.00
Labor, moving and wrecking 7 bents	2,843.00
Materials for 17 bents:	
Yellow pine, 469 M., at $27.50	12,910.00
Yellow pine, 31 M., at $20	632.00
Iron bolts, etc., 39,501 lbs	1,351.00
Materials for truss:	
Yellow pine, 10.8 M., at $27.50	297.00
Rods, 21,100 lbs	740.00
Plant total	2,000.00
Total	$33,409.00
General expenses, 10%	3,341.00
Grand total	$36,750.00

Total Cost of Traveler.

Labor, building and wrecking	3,895.00
Materials:	
Yellow pine, 46.4 M., at $27.50	1,278.00
Iron bolts, etc., 14,740 lbs	420.00
Rods, 5,500 lbs., at 3½ cts	193.00
Tackle, 20,000 lbs., at 4 cts	800.00
Plant	340.00
Total	$6,926.00
General expense, 10%	693.00
Grand total	$7,619.00

Total Cost of 20-Ton Derrick.

Labor, building and wrecking	$647.00
Materials	600 00
Plant	50.00
	$1,297.00
General expenses, at 10%	129.00
Total	$1,426.00

Total Cost of False Work for End Span Containing 2,636 Tons of Steel.

	Per Ton Steel Erected.	Total.
Pile trestle	$5.70	$15,040.00
Timber false work	13.94	36,750.00
Traveler	2.90	7,629.00
20-ton derrick	.54	1,426.00
Total	$23.08	$60,845.00

The total weight of steel erected in intermediate tower and end span was 2,636 tons; the false work, therefore, cost $23.08 per ton of steel.

It should be noted that no salvage has been allowed for timber and iron, as there was no means of determining what was the ultimate value of this material.

Cost of Erection of Main Towers.—Erection of main towers was begun Feb. 1, 1900, and was completed, with the exception of placing the saddle on top of the tower on Oct. 1st of the same year. The last saddle was set Dec. 14. The first section erected, which extended up to the roadway level, or to elevation 125 ft. above mean high water, contained the heaviest members, and should have been the cheapest to erect. The delivery, however, was slow and the organization not yet perfected. The second section erected extended to elevation 232 ft. above mean high water, and contained a great deal of light and intricate cross bracing, which accounts for its higher cost. In the top section the steel was delivered promptly, and the construction was simple and free from detail work.

The prices paid to labor, per day of 8 hours, were as follows:

Foremen	$5.00
Sub-foremen	3.75
Hoisters	3.50
Steelmen	3.50
Laborers	2.00

The plant consisted of two 40-hp. 10-in. x 12-in. boilers, one 25-hp. 8-in. x 10-in. double-cylinder, 4-drum engine, and one small donkey engine. Charging these off at 50%, the total plant charge, including steel cable, rope, small tools, coal, etc., was $5,000.

The cost given in Table X does not include the cost of riveting, which is treated separately.

The incidental expenses were as follows:

Preliminary work	$ 637
Fitting steel at top of towers, chipping roller beds, etc.	1,221
Placing anchor bolts	45
Diamond-drilling 32 anchor-bolt holes	4,000
Rust joints materials	931
Total	$6,814

Erecting End Span.—This work consisted of erecting the intermediate tower and the land truss, which extended from the main towers to the anchorage, a distance of 600 ft. The truss was 40 ft. deep by 67 ft. wide, with a roadway 25 ft. in width extending beyond the truss on each side. The span was made up of two heavy trusses, divided into 20-ft. panels, and complicated with a multitude of details owing to the various kinds of traffic that had to be taken care of on this bridge.

The intermediate tower on which the cantilever span rested was 90 ft. in height, and rested on two masonry piers 67 ft., center to center. Each pier supported four steel columns, with diagonal bracing and connected across at the top with heavy beams. All material was brought to the site on floats, and was unloaded by means of a derrick situated at the main tower. The material was placed on flat cars, which ran on a trestle about 6 ft. above mean high water, and was pushed by hand to the foot of the false work extending just beyond the intermediate towers. Here it was hoisted to cars running on top of the false work and placed under the traveler, which erected it in position.

The erection of the intermediate tower was begun in April, 1900. The erection of the end span was finished in March, 1901. The cost of labor was the same as for the main tower, with the exception of the hoisters, runners and steelmen, whose rate was increased to $3.76 per day of eight hours.

The plant consisted of three second-hand 25-hp. engines, double-cylinder 8 in. x 10 in., with six drums and boilers, and cost, at 50%, $1,500. The cost of rope, small tools, etc., was $1,300, making the total cost $2,800. The total cost of erection is given by Table XI.

The incidental expenses were:

Preliminary work	$ 500
Rust joints	150
Adjusting errors in steel work	696
Removing steel for cables	1,006
Total	$2,352

Riveting on Main Towers and End Span.—The riveting was done with pneumatic riveters; from four to eight guns were generally in use. Four men, including the rivet heater, constituted a gang; each man received $3.76 per day of eight hours. Compressed air was furnished at about 80 lbs. pressure by two compressors, with a combined capacity of about 300 cu. ft. per minute. The rivets used on the intermediate tower were short and easily driven, as indicated by the cost given in Table XII, while the heavy sections

TABLE X.—COST OF ERECTING MAIN TOWERS.

	1st Section. 987 Tons.		2d Section. 795 Tons.		3d Section. 1,236 Tons.		Total. 3,018 Tons.	
	Per Ton.	Total.	Per Ton.	Total.	Per Ton.	Total.	Per Ton.	Total.
Unloading and handling	$0.76	$ 748.00	$ 0.91	$ 721.00	$0.37	$ 467.00	$0.64	$ 1,936.00
Erecting	2.64	2,608.00	4.45	3,541.00	2.55	3,149.00	3.08	9,293.00
Plant charge	1,67	1,650.00	1.63	1,300.00	1.66	2,050.00	1.65	5,000.00
Plant labor	.46	462,00	.46	364.00	46	574.00	.46	1,400.00
Incidental expenses	2.27	2,244.00	2.23	1,770.00	2.26	2,800.00	2.26	6,814.00
Total	....	$7,712.00	....	$7,696.00	....	$9,040.00	....	$24,448.00
General expenses, 10%	$0.78	771.00	$ 0.97	769.00	$0.73	904.00	$0.81	2,444.00
Total	$8.53	$8,483.00	$10.65	$8,465.00	$8.03	$9,944.00	$8.90	$26,892.00

TABLE XI.—COST OF ERECTING INTERMEDIATE TOWER AND END SPANS.

Weight—	Intermediate Tower. 339 Tons.		Cantilever Span. 1,333 Tons.		Connecting Span. 964 Tons.		Total. 2,636 Tons.	
	Per Ton.	Total.	Per Ton.	Total.	Per Ton.	Total.	Per Ton.	Total.
Unloading and handling steel	$0.31	$ 107.00	$ 0.90	$ 1,201.00	$0.56	$ 542.00	$0.70	$ 1,850.00
Erection of steel	2.69	912.00	6.67	8,892.00	3.69	3,559.00	5.07	13,363.00
Plant	.99	336.00	1.09	1,454.00	1.05	1,010.00	1.06	2,800.00
Plant, labor	.50	168.00	.54	727.00	.52	505.00	.53	1,400.00
Incidentals	.83	282.00	.92	1,224.00	.87	846.00	.89	2,352.00
Total	....	$1,805.00	....	$13,498.00	....	$6,462.00	....	$21,765.00
General expenses, 10%	$0.53	180.00	$1.01	1,350.00	$0.67	646.00	$0.82	2,176.00
Total	$5.85	$1,985.00	$11.13	$14,848.00	$7.36	$7,108.00	$9.07	$23,941.00

TABLE XII.—COST OF RIVETING.

No. Rivets Driven, Net.	Main Towers. 100,039		Intermediate Tower. 18,971		End Span. 91,835		Total. 210,845	
	Per Rivet.	Total.	Per Rivet.	Total.	Per Rivet.	Total.	Per Rivet.	Total.
Total, labor	$0.158	$15,874.00	$0.085	$1,609.00	$0.159	$14,631.00	$0.152	$32,114.00
Labor, scaffolds	.021	2,071.00	.003	64.00	.005	465.00	.012	2,600.00
Plant	.046	4,615.00	.045	865.00	.045	4,130.00	.045	9,610.00
Total	....	$22,560.00	......	$2,538.00	......	$19,226.00	......	$44,324.00
General expenses, 10%	$0.022	2,256.00	$0.013	254.00	$0.02	1,922.00	$0.021	4,432.00
Total	$0.247	$24,816.00	$0.146	$2,792.00	$0.229	$21,148.00	$0.23	$48,746.00

on the main tower and end span required long heavy rivets, which were very difficult to drive. The plant consisted of the following:

2 boilers, at 50%	$ 300
2 compressors, at 50%	1,300
9 pneumatic rammers, at 50%	1,800
15 forges, at 50%	250
W. I. pipe	200
Coal	1,120
Steel, tools, scaffold, etc.	1,350
Plant, labor, miscellaneous	3,290
Total	$9,610

Painting Main Tower and End Span.—The cost of the first coat of paint on the main tower and end span was about double what it should have been on account of the bad condition of the shop coat, which had to be scraped off in many places before the first coat could be applied. A fair average would be to figure painters employed one-half time in preparing the surface.

TABLE XIII.—COST OF PAINTING STRUCTURE.

	Main Tower, 3,071 Tons.		End Span. 2,636 Tons.		Total. 5,707 Tons.	
	Per Ton.	Total.	Per Ton.	Total.	Per Ton.	Total.
First coat	$1.03	$3,163	$1.99	$ 5,235	$1.47	$ 8,398
Second coat	.60	1,847	.88	2,325	.73	4,172
Total labor	$1.63	$5,010	$2.87	$ 7,550	$2.20	$12,570
Materials	.52	1,600	.52	1,363	.52	2,963
Plant	.31	960	.31	815	.31	1,775
Total		$7,570	....	$ 9,738	....	$17,308
General exp., at 10%	$0.25	757	$0.37	974	.30	1,731
Grand total	$2.71	$8,327	$4.07	$10,712	$3.33	$19,039

Painters received $2.25 per day of eight hours, but painted only the first coat on the main tower. After that steelmeen were employed at $3.76 per day. Table XIII shows the cost of painting. The cost of the plant was as follows:

Brushes, pots, etc.	$ 214
Scaffolds, ladders, etc.	313
Anchorage protection	345
Miscellaneous plant labor	903
Total	$1,775

General Expense.—The general expense on this work includes the resident engineer, draftsman, superintendent, timekeepers, office help and watchman; and figured out 10% to the cost of the total labor and materials employed at the site of the work.

As previously noted, the large cost for falsework is brought about on account of not crediting salvage on the materials on this item. Table XIV gives the total cost of the completed work.

TABLE XIV.—TOTAL COST OF COMPLETED WORK.

	Main Tower. 3,071 Tons.	End Span. 2,636 Tons.	Total 5,707 Tons.	Cost Per Ton.
Falsework	$25,583	$ 60,845	$ 86,428	$15.19
Erection	26,892	23,941	50,833	8.95
Riveting	24,816	23,940	48,756	8.55
Painting	8,327	10,712	19,039	3.31
Total	$85,618	$119,438	$205,056	......
Cost per ton	$28.05	$45.30	$36.00	$36.00

The materials used in painting main tower and end span were as follows:

28 bbls. No. 500 National Paint Works	$1,640
24 bbls. No. 20 National Paint Works, Spec.	1,103
Turpentine	60
Linseed oil	160
Total	$2,963

Cost of the Brooklyn Anchorage of the Williamsburg Bridge.—The following data were given by Mr. Francis L. Pruyn, in *Engineering-Contracting,* Jan. 30, 1907:

The Brooklyn anchorage of the Williamsburg Bridge consisted essentially of a block of masonry 150 ft. long, 182 ft. wide and 114 ft. high. Its function was to furnish sufficient weight to hold down the cables when the main span of the bridge was fully loaded. Fig. 1 [too large for reproduction here] shows the main feature of the design; which included an excavation 40 ft. deep, a pile and timber grillage foundation, over which was spread a 14-ft. layer of concrete. From this point to the elevation of the ground, a distance of 25 ft., limestone masonry was placed, and from this elevation to the top of the anchorage the masonry consisted of limestone backing with granite face-stone.

The interior of the anchorage contained three tunnels extending from top to bottom in which were placed the steel anchor chains. These chains were fastened at the bottom of the anchorage to a heavy steel grillage which was firmly imbedded in the masonry. The anchorage also contained two large wells situated between the lines of anchor chains, which were necessary in order to obtain an equal load distribution on the foundation. The main items in this contract were as follows:

Earth excavation	34,000 cu. yds.
Yellow pine piles	432
Yellow pine timber	120,000 cu. ft.
Concrete	10,885 cu. yds.
Stone masonry	44,597 cu. yds.
Steel anchor chains	1,553 tons.

Cost of Excavation.—The anchorage was situated about 360 ft. from the East River bulkhead line and a trestle was constructed to carry the excavated material across the intervening street to a dumping-board, where it was loaded directly into scows and carried away to sea. Tracks were laid on this trestle and cars which

were actuated by an ingenious form of cable haul handled the excavated material. This trestle and hauling device also served to handle all the material for grillages, concrete, stone masonry, steel work, etc.

The excavation was done by pick and shovel into skips, which were elevated and placed on the cars by means of eight derricks arranged around a framework, which was maintained at the original ground level. Long piles were driven before the framework was erected to support it as the excavation proceeded, and these piles were braced and spliced as the ground level receded. This feature of the plant was very expensive, as the proper support of this heavy framework kept a large gang of men continually at work. Derricks placed around the edges of the excavation would have proved much more economical, not only on account of needing less maintenance, but also because they would have covered the entire work whereas the derrick frame could not reach the area directly under itself. The derricks were designed without bull wheels so that tag men had to be used throughout. This feature added 6 per cent to the cost of excavation for labor alone, and probably added as much more through loss of time in swinging derricks.

On two sides of the excavation 10 x 12-in. yellow pine sheet piling 30 ft. long was driven to protect sewers, water pipes, etc., in the adjoining streets. The driving was exceedingly difficult and hard, it being through sand and gravel. The piles were often broken in driving and the points of many were found badly broomed when uncovered. The following rates of wages were paid per 10-hour day:

	Per day.
Foreman	$4.00
Hoister	2.50
Fireman	2.00
Carpenter	2.50
Riggers	2.25
Laborers	1.75

The average length of sheet piles was 30 ft.; 8,000 lin. ft. were driven and 9,000 lin. ft. used. The total cost of the sheet piling was as follows, no salvage being credited:

	Total cost.	Cost per lin. ft.
Labor, driving	$1,405	$0.176
Labor, bracing	920	0.115
Piles, 90 M at $20	1,800	0.225
Bracing, 100 M at $13	1,300	0.163
Plant	234	0.029
Steam	133	0.016
Total	$5,792	$0.724

After the sheeting was driven the excavation was covered down to the required depth of 40 ft. below the elevation of the ground. About one-half the material excavated was sand, and the remain-

der was made up of clay and hard pan. About one-quarter was hard pan and very hard digging. All excavation was done by hand, the material being shoveled into skips, which were then raised by the derricks and placed on flat cars which ran through the derrick frame. The cars were then run to the dump about 400 ft. distant by a cable device, the material being dumped down an incline chute into scows, to be dumped at sea. Building sand, sufficient for all concrete and masonry on this work, was secured from the excavation and stored on the work. The rates of wages paid per 10-hour day were as follows:

	Per day.
Hoisters	$2.75
Signalmen	2.00
Tagman	1.50
Trackmen	1.75
Laborers	1.60

The labor cost of excavating 42,000 cu. yds. was as follows:

Labor.	Amt.	cu. yd.
Loading skips	$ 8,000	$0.19
Loading on cars	2,184	0.05
Dumping	2,879	0.07
General foreman	875	0.02
Total	$13,938	$0.33

The total cost of excavation was as follows:

	Quantity cu. yds.	Total cost.	Cost per cu. yd.
Labor	42,000	$13,938	$0.332
Pumping	42,000	1,176	.028
Steam	42,000	1,763	.042
Plant	42,000	11,140	.265
General expenses	42,000	5,585	.133
Dumping at sea	22,000	3,300	.105
Total		$36,900	$0.90

The cost of pumping, steam, plant and general expenses were figured for the entire work and distributed through each item separately, as is shown further on. The best month's run constituted 16,351 cu. yds., working 67 ten-hour shifts, which is equivalent to 246 cu. yds. per 10-hour day. The average output for the entire period of excavation was 184 cu. yds. per 10-hour day, which is equivalent to 218 working days for this portion of the work. It will be noted that the plant charges are exceedingly high, and include the sheet piling given above as well as its proportionate charge of derrick frame, trestle, etc.

Foundation Piles.—After the excavation was completed, foundation piles were driven in three clusters under the steel grillages. There were 423 piles in all, and as the bottom consisted of pure sand saturated with water they could not be driven more than an average of 9 ft. below cut-off. The cost of driving these piles is excessive owing to the great difficulty encountered in driving un-

der the derrick frames, which were directly over about 20 per cent of them.

	Total cost.	Cost per pile.
Labor, driving	$ 731	$1.73
Piles, 13 ft. long	634	1.50
Pumping	376	0.87
Steam	35	0.08
Plant	213	0.50
General	348	0.82
Total	$2,337	$5.50

Timber Grillage.—Over the entire foundation and around the heads of the piles was deposited a 2-ft. layer of concrete in which was imbedded the first course of timber that constituted the grillage, covering the entire area of foundation and consisting of four thicknesses of 12 x 12-in. yellow pine timber. The timber was sized top and bottom and drift bolted every 6 ft. with 1⅛-in. drift bolts. The top course of timber consisted of alternate rows of 8 x 12 in. and 10 x 12 in. to bond with the concrete. The cost of the timber grillages was as follows, there being 1,394 M ft. B. M. of timber:

Labor.	Total Amount.	Per M ft. B. M.
Delivery to anchorage	$ 1,660	$ 1.19
Placing	2,437	1.75
Drift bolting	920	0.66
General foreman	490	0.35
Total	$ 5,507	$ 3.95

Total cost.	Total Amount.	Per M ft. B. M.
Labor	$ 5,507	$ 3.95
Yellow pine	25,090	18.00
Iron	3,900	2.80
Pumping	1,394	1.00
Steam	83	.06
Plant	1,990	1.43
General	2,092	1.50
Total	$40,056	$28.74

Concrete.—A layer of concrete varying in thickness from 6 to 10 ft. and covering the entire foundation was deposited above the timber grillage. About 8,200 cu. yds. was required, the mixture being about one part cement to two parts of sand to five parts broken stone. The concrete was mixed in a 2 cu. yd. cubical mixer situated directly beneath the derrick frame, so that the materials could be dumped from cars into the mixer hopper. Broken stone came to the site in barges and was shoveled into skips, and after the required amount of cement was spread on the stone, the skip was lifted by a derrick onto cars situated on the trestle. The car was then hauled by cable to the mixer and dumped, with the required amount of sand for a batch. The mixed concrete was run into buckets and deposited in the work by derricks, where it was

spread and rammed in 12-in. layers. A batch consisted of 2¼ barrels of cement, 19 cu. ft. of sand and 47 cu. ft. of broken stone and made 1.8 cu. yd. in place. The maximum output for 10 hours was 111 batches or 200 cu. yds.; the average output for the entire time of concreting, or 67 days, was 68 batches, or 122 cu. yds.

The average force was 51 men divided as follows: 15 hauling materials, 12 placing, 3 mixing; the rest were hoisters, runners, signal men, car men, etc. The rates of pay were the same as those previously given. The cost of 8,169 cu. yds. of concrete was as follows:

Labor.	Total.	Per cu. yd.
Handling materials	$ 2,660	$0.32
Mixing	348	0.04
Placing	3,003	0.38
General foreman	512	0.06
Total	$ 6,523	$0.80

Total cost.	Total.	Per cu. yd.
Labor	$ 6,523	$0.80
Cement, at $1.50 per bbl.	15,930	1.95
Sand, at $0.50 per cu. yd.	1,630	0.20
Stone, at $1.25 per cu. yd.	9,800	1.20
Pumping	1,553	0.19
Steam	490	0.06
Plant	4,495	0.55
General expenses	2,460	0.30
Total	$42,881	$5.25

The concrete was of large mass and was easily placed. The plant was well designed and the job well managed. The plant charge of 55 cts. per cu. yd. was high; one-half of it was chargeable to the derrick frame. This part of the plant, as before stated, was expensive to maintain and the proportion chargeable to concrete was therefore large.

Masonry.—The stone masonry, consisting of a total of 44,000 cu. yds., was for the most part in large masses; at the same time the tunnels for the anchor chains and the various wells required a good deal of careful setting. The masonry from the concrete up to about ground level consisted of a face of rock-faced limestone with limestone backing. At the ground level came several courses of six-cut granite facing 16 ft. in height, above this came rock-faced granite facing up to the coping courses, which were of six-cut granite. All backing was of limestone, roughly squared, in thickness equal to the face stones of the same course and with vertical joints that averaged 3 ins. The vertical and horizontal joints of all rock-faced ashlar was ½ in.; for six-cut work it was ¼ in.

The stone was unloaded from barges at the dock onto cars, which were hauled by cable to the site of the work. The mortar was mixed by machine in the concrete mixer.

The cost of labor in setting masonry was high and was due to the design of the derrick frames, which were directly over the work. They had to be jacked up for each course above the ground level, which was expensive, and being located over the center of

this work, setting stone beneath them was difficult and costly. Tagmen were used to swing the derricks; as the design did not permit bull wheels; they added 15 cts. per cu. yd. to the cost of setting. Stone masons worked an 8-hour day, all other labor a 10-hour day. The labor rates were as follows:

	Per day.
Foreman	$5.00
Masons	3.20
Signal men	2.00
Laborers	1.50

The total labor cost of setting 44,053 cu. yds. of masonry was:

	Total.	Per cu. yd.
Delivering stone	$ 9,935	$0.23
Mixing and delivering mortar	8,792	0.20
Delivering spalls	965	0.02
Setting stone	41,141	0.94
Total	$60,833	$1.39

In the following cost of the various kinds of masonry, the labor was taken at $1.39 per cu. yd., as above given; there was no means of obtaining the cost of setting the various classes of masonry. Likewise the percentage of mortar was taken at a fixed percentage of the total masonry. Actually the mortar varied from 15 per cent in backing to 6 per cent in rock facing, to 2 per cent in six-cut work. The difference in cost of mortar, however, is more than balanced by the extra cost of setting the facing and six-cut masonry. The cost of mortar per cu. yd. of masonry was:

	Per cu. yd.
0.4 bbl. cement at $1.50	$0.60
0.12 cu. yd. sand at $0.50	0.06
	$0.66

The cost of limestone backing 34,200 cu. yds. was:

	Total.	Per cu. yd.
Labor	$ 47,538	$1.39
Mortar	22,572	0.66
Stone, $5 at 85%	145,350	4.25
Steam	4,788	.14
Plant	26,340	.77
General expenses	16,760	.49
	$263,348	$7.70

The cost of limestone facing 3,500 cu. yds. was:

	Total.	Per cu. yd.
Labor	$ 4,860	$1.39
Mortar	2,310	.66
Stone, $7.25 at 94%	23,805	6.80
Steam	490	.14
Plant	2,695	.77
General expenses	1,715	.49
	$35,875	$10.25

The cost of granite facing 3,523 cu. yds. was:

	Total.	Per cu. yd.
Labor	$ 4,900	$ 1.39
Mortar	2,325	.66
Stone, $16.66 at 95%	55,170	15.66
Steam	494	.14
Plant	2,715	.77
General expenses	1,730	.49
Total	$67,334	$19.11

The cost of granite backing 700 cu. yds. was:

	Total.	Per cu. yd.
Labor	$ 973	$ 1.39
Mortar	462	.66
Stone, $14.47 at 88%	8,925	12.75
Steam	98	.14
Plant	639	.77
General expenses	343	.49
Total	$11,340	$16.20

The granite knuckle stone, 300 cu. yds., cost:

	Per cu. yd.
Labor	$ 1.39
Mortar	....
Stone	17.68
Steam	.14
Plant	.77
General expenses	49
Total	$20.47

The six-cut granite, 1,640 cu. yds., cost:

	Per cu. yd.
Labor	$ 1.39
Mortar	.66
Stone, $28.67 at 98%	28.05
Steam	.14
Plant	.77
General expenses	.49
Total	$31.50

Cost of Erecting Steel.—The steel work consisted of a heavy grillage made up of beams 5 ft. 6 ins. deep by 36 ft. and 24 ft. long, riveted together to form an anchorage for each set of anchor chains, and of four chains made up of 2-in. eye-bars from 10 to 14 ft. long. Each chain extended from the top to the bottom of the anchorage and was made up of two rows of 20 eye-bars and fastened together with 6-in. steel pins. The steel was delivered in the same manner as the other materials and set in place by derricks. Each pin rested on a heavy casting or steel girder, which rested upon knuckle stones, cut to the proper angles and set in the masonry. The joints between the knuckle stone and the

bearing girders were rust joints. The total weight erected was 1,583 tons, and the cost of erection was as follows:

Labor:		
Delivery and erection	$3,337	
Riveting	1,384	
Painting	962	
Drilling for bolts	349	
Rust joints	282	
Foremen	675	
Total labor	$6,989	$4.42 per ton
Steel		65.00 per ton
Plant		2.06 per ton
Steam		.06 per ton
General expenses		.44 per ton
Total		$71.98 per ton

Steam Production.—The cost of fuel and labor for steam production for the whole work is as follows. The boiler battery consisted of four old Manhattan Elevated locomotive boilers of 30 hp. each. They were located near the dock and the steam was piped to the anchorage.

Foreman, day, 25½ mos. at $85	$2,170	
Foreman, night, 25½ mos. at $60	1,530	
Helper, 25½ mos. at $40	1,020	
		$ 4,720
2,340 long tons soft coal at $2.25	$5,360	
1,525 long tons hard coal at $4.00	6,100	
		$11,360
		$16,080

This cost has been distributed through the different classes of work

Pumping.—Pumping was done during part of the time that excavation, pile driving, concreting and timber grillage work was being done, a total of 235 days. The cost was as follows:

Engineers, 466½ days at $2.85	$1,330
Laborers, 202½ days at $1.50	303
Total	$1,633
Steam	3,964
Plant	990
Total cost	$6,587

Plant.—The plant cost for the various kinds of plant and machinery described under the different classes of work were as follows; no salvage has been credited:

	Materials.	Labor.	Total.
2 Derrick frames, complete	$ 8,538	$ 8,052	$16,590
2 Derrick frames, repairs	8,321	11,574	19,895
Trestle and track	4,117	1,626	5,743
Boiler, battery	1,140	134	1,274
Pumping	990	268	1,258
Pile driver	2,590	.....	2,590
Mixer and trestle	612	426	1,038
2 Derricks at bulkhead	2,321	448	2,769
1 Howe truss	480	517	997
1 Derrick for sand	703	52	755
Sewer	120	158	278
Gutter	35	28	63
Electric light	2,000	....	2,000
Water for motor	500	.....	500
Water for steam	.....	1,280	1,280
Waterproofing	260	.....	260
Total	$33,817	$24,563	$58,380

General Expenses.—The general expenses were made up as follows:

Office force and watchman, 21 mos., at $922.50	$19,395
Making bid, say	500
Money invested, say $50,000, at 5%, for 21 mos.	4,400
Bond, $350,000, at 1%	6,125
Insurance, $140,000, at 3%	2,800
Traveling expenses, say	500
Office rent	1,825
Building office and storeroom	800
Office fixtures	400
Office stationery, telephone, etc.	1,000
Total	$37,745

Labor Cost of the Foundations of City Island Bridge, New York.* Before giving the figures of the cost of labor in the construction of the foundations of the City Island Bridge, it will be well to give a brief description of the bridge itself. The City Island Bridge connects City Island and Pelham Bay Park at Rodman Neck, Bronx Borough, New York. It is about 1,500 ft. long, including approaches, and 50 ft. wide over all. There are six masonry piers and two abutments, all sunk to rock or hard material at a maximum depth of 40 ft. below high water, and they support the steel superstructure. The superstructure proper consists of a 180-ft. draw span and five 80-ft. spans. The pivot pier, which has a maximum diameter of 35 ft., is protected by a longitudinal crib, 228 ft. long and 51 ft. wide. The pier has 45 degree cutwater ends and is sheathed with 4-in. yellow pine vertical planks, 14 ft. long, which extend from 1 ft. below mean water level to the top of the crib, 5 ft. above mean high water. The pivot pier occupies a rectangular space, 63 ft. long and 37 ft. wide. The bridge was built for the Department of Bridges, New York City, the superstructure being

* *Engineering-Contracting,* May 16, 1906.

constructed by the King Bridge Co., and the substructure by John F. O'Rourke.

Cofferdams.—A subcontract for the construction of the cofferdams was let by John F. O'Rourke, the contractor for the foundations, to Warren Rosevelt, New York. The material used was yellow pine. The lower sections of the cofferdams, which remained in the permanent work, were constructed upon ways and launched. The upper section was then constructed. Several pile driving scows were used on the work. In the placing of the cofferdams, the plant was furnished by Mr. Rosevelt; but Mr. O'Rourke furnished the laborers for loading bags of gravel to sink and place them. In the summary, Table XV, which gives the time for constructing the cofferdams and the amount of material used, it will be noticed that the dam for abutment No. 1 was constructed in a less period than any of the others. This was due in a measure to better facilities for handling the material. The higher cost for building the cofferdam for Pier No. 3 (pivot pier) was due to the fact that it was built in an octagonal form. No data were obtained of the cost of setting the cofferdam for pier No. 3.

Masonry.—According to the specifications, the masonry was classified in two grades: (1) Foundation masonry and (2) pier masonry. Blue gray limestone, or other dark stone of compact granular structure without lamination, was to be used in both cases. The backing of the abutment masonry, to mean high water, was to be concrete in the proportion of 1 : 2 : 4. Above mean high water the proportion of concrete was to be 1 : 3 : 5. The foundation masonry was to be laid to the elevation of mean low water, and was to consist of first-class quarry-faced ashlar bedded in Portland cement mortar with ¾-in. joints, and well rammed concrete backing of 1 : 2 : 4 concrete. Work was to be laid in regular courses, 24 in. to 30 in. in depth, with thickness progressively diminishing upward. All stones were to be cut to line on their natural beds, and the top surface had to be parallel with its bed. Beds were to be dressed the entire width of the stone and vertical joints cut back not less than 12 in. Courses were to break joints with each other at least 12 in., and headers were to be arranged so as to come over underlying stretchers. Not less than one header to every two stretchers was to be used. The concrete backing was to be leveled up with each course of stone. The stones for the pier masonry were to be cut to dimension, and laid with joints not exceeding ½ in. The hearting or backing was to consist of 1 : 2 : 4 concrete for abutment to elevation of mean high water; 1 : 3 : 5 concrete was to be used above that elevation. The coping was to consist of selected limestone or light colored granite, quarry faced, laid with ¼-in. joints.

As a matter of fact, the stone used for the masonry was Cobbleskill limestone facing with concrete backing. The coping was granite from Maine. The masonry work was done by John F. O'Rourke, the contractor. The plant consisted of two derrick scows and stiff leg derrick, the latter being used on abutment No. 1 and pier No. 3. One of the scows was used mainly in depositing concrete

TABLE XV—CONSTRUCTION OF COFFER DAM.

Workmen.	Rate per hr., cts.	Number of Hours. Abut. No. 1	Pier No. 2	Pier No. 3	Pier No. 4	Total hrs.	Cost of Labor. Abut. No. 1	Pier No. 2	Pier No. 3	Pier No. 4	Total.	Cost of Labor per M ft. B. M. Abut. No. 1	Pier No. 2	Pier No. 3	Pier No. 4	Average.
Superintendent	89¼	122	104	94	124	444	$108.88	$92.82	$83.90	$110.67	$396.27	$2.60	$3.47	$2.73	$4.23	$3.18
Foreman	45	172½	172½	186	155	686	77.62	77.62	83.71	69.75	308.70	1.92	2.90	2.72	2.68	2.48
Engineman	32½	167½	187½	202	155	712	54.43	60.94	65.65	50.37	231.39	1.33	2.27	2.14	1.93	1.86
Deck Builders	30	1,767½	1,280	1,977	1,270	6,294½	530.25	384.00	593.10	381.00	1,888.35	13.00	14.35	19.30	14.61	15.17
Pile Drivers	30	235	157½	222½	165	780	70.50	47.25	66.75	49.50	234.00	1.73	1.76	2.14	1.90	1.88
Watchman	20	130	310	196	230	866	26.00	62.00	39.20	46.00	173.20	.64	2.31	1.28	1.76	1.39
Laborers	20	.....	20	.....	....	20	......	4.00	......	......	4.00	.....	.15	.....	.....	.03
Total							$867.68	$728.63	$932.31	$707.29	$3,235.91	$21.31	$27.21	$30.31	$27.11	$25.99

SETTING COFFER DAM.

Workmen.	Rate	Number of Hours. Abut. No. 1	Pier No. 2	Pier No. 4	Total.	Cost of Labor. Abut. No. 1	Pier No. 2	Pier No. 4	Total.	Average Hrs. per M ft. B. M.	Cost of Labor per M ft. B. M. Abut No. 1	Pier No. 2	Pier No. 4	Average.
Rosevelt's Superintendent	89¼	5	4	6	15	$4.46	$3.57	$5.35	$13.38	0.16	$0.11	$0.13	$0.20	$0.14
" Foreman	45	5	5	7½	17½	2.25	2.25	3.37	7.87	0.18	.05	.08	.13	.08
" Engineman	32½	10	5	7½	22½	3.25	1.62	2.43	7.30	0.24	.08	.06	.09	.07
" Deck Builders	30	30	50	67½	147½	9.00	15.00	20.25	44.25	1.57	.22	.56	.80	.47
" Pile Drivers	30	..	5	15	20	....	1.50	4.50	6.00	0.21	...	.06	.17	.06
O'Rourke's Superintendent	70	6	8	4	18	4.20	5.60	2.80	12.60	0.19	.10	.21	.10	.13
" Foreman	35	6	10	10	26	2.10	3.50	3.50	9.10	0.28	.05	.13	.13	.09
" Laborers	15	60	100	100	260	9.00	15.00	15.00	39.00	2.78	.22	.56	.58	.42
" Time Keeper	40	4	5	4	13	1.60	2.00	1.60	5.20	0.16	.04	.07	.06	.05
Total						$35.86	$50.04	....	......	....	$0.87	$1.86	$2.26	$1.51

CONSTRUCTION OF THE COFFER DAM—SUMMARY.

	Begun 1899	Finished 1899	Ft. B. M. Upper.	Lower.	Total.
Abutment No. 1	Aug. 16	Sept. 5	12,955	27,770	40,725
Pier No. 2	July 8	July 31	8,485	18,273	26,758
Pier No. 3	May 8	June 16	8,186	22,478	30,664
Pier No. 4	Aug. 1	Aug. 25	8,496	17,557	26,053

TABLE XVI.—MASONRY WORK.

Workmen.	Rate	Number of Hours. Abut. No. 1	Pier No. 2	Pier No. 3	Pier No. 4	Total Hrs.	ost of Labor. Abut. No. 1	Pier No. 2	Pier No. 3	Pier No. 4	Total	Average Hrs. per Cu. Yd.	Cost per Cubic Yard. Abut. No. 1	Pier No. 2	Pier No. 3	Pier No. 4	Average.
Superintendent	70 50	128	74	80	75	457	$64.60	50.60	$56.00	$48.30	$219.50	0.25	$0.10	$0.21	$0.08	$0.20	$0.12
Foreman	35	180	75	109	5	369	63.00	26.25	38.15	1.75	129.15	.20	.09	.11	.06	.01	.07
Mason	40	475	168	388	283	1,314	190 00	67.20	153.20	113.20	525.60	.73	.29	.28	.23	.46	.29
Stone Cutter	50	300	310	24	360	994	150.00	155.00	12.00	180.00	497.00	.55	.23	.64	.02	.74	.27
Engineman	30	269	154	247	216	886	114.30	46.20	74.10	64.80	299.40	.19	.18	.19	.11	.27	.17
Laborers	15 20	2,988	916	1,700	1,227	6,831	449.60	139.20	340.00	184.05	1,112.85	3.77	.68	.57	.51	.76	.61
Timekeeper	30 40	99	49	112	67	327	29.90	19.50	44.80	25.40	119.60	.18	.04	.08	.07	.10	.07
Carpenter	20	20	...	....	....	20	4.00	......	......	......	4.00	.01	.01	....	....	....	.00
Driver	50	....	...	60	....	60	......	......	30.00	......	30.00	.03	....	....	.05	....	.02
Total							$1,065.40	$503.95	$750.25	$607.50	$2,937.10	...	$1.62	$2.08	$1.12	$2.54	$1.62

MASONRY SUMMARY.

	Begun 1899.	Finished 1899.	Masonry, Cubic Yards.	Per Cent Concrete Backing.	Per Cent Lime-stone Facing.	Per Cent Granite Masonry.
Abutment No. 1	Oct. 29	Dec. 20	659.67	44	50	6
Pier No. 2	Oct. 10	Dec. 8	243.54	16	75	9
Pier No. 3	Aug. 29	Sept. 16	667.11	58	35	7
Pier No. 4	Oct. 17	Dec. 9	243.54	15	76	9

backing. The foregoing table of cost for masonry work is for building the masonry after the material was loaded on the scows, and does not include the handling of material, placing stone from yard on scows and cement from the storehouse.

The higher cost of the construction of masonry of pier No. 2 and pier No. 4 will be explained by an examination of the Summary Table, which shows the proportion of backing and face stones.

Granite Cutting.—In this work the material was furnished by Mr. O'Rourke, but the labor was done by a sub-contractor. The granite was brought by vessel from Maine and was used in coping, bridge seats and abutment steps. Beds were peenhammered and the faces rock faced. A total of 7,052 cu. ft. was cut. Eight hours constituted a day's work.

In the table below is given the labor cost of cutting the granite

TOTAL COST OF CUTTING GRANITE.—(7,052 CU. FT.)

		Number of Hours.			Cost of Labor.		
Workmen.	Rate.	Total.	Per cu. ft.	Per cu. yd.	Total.	Per cu. ft.	Per cu. yd.
Foreman	60	517	.07	1.98	$ 310.20	$0.04	$ 1.19
Stonecutters	50	4,718	.67	18.10	2,359.00	.34	9.05
Carpenters	25	8	.00	.03	2.00	....	.01
Laborers	20	984	.14	3.78	196.80	.03	.76
Blacksmith	25	286	.04	1.10	71.50	.01	.27
Engineman	30	443	.06	1.70	132.90	.02	.51
Total					$3,072.40	$0.44	$11.79

for coping and steps. This work was included in the table that precedes this paragraph, but as the details were obtained from a different source of information, it has been thought well to give it here.

LABOR OF STONECUTTERS ONLY.

	Cu. Ft.	Hours Worked.	Cu. Ft. Per Hour.	Cost Per Cu. Ft.	Cost Per Cu. Yd.
Abutment No. 1	1,041-10 in.	511	2.042	$0.245	$ 6.62
Pier No. 2......	462- 8 in.	341	1.358	.368	9.94
Pier No. 3......	625- 6 in.	394	1.589	.354	9.55
Pier No. 4......	446- 2 in.	312	1.432	.349	9.42
Pier No. 5......	454- 5 in.	286	1.592	.314	8.48
Pier No. 6......	121- 0 in.	99	1.222	.408	11.04
Pier No. 7......	121- 0 in.	98	1.235	.405	10.93
Abutment No. 8*	734- 5 in.	409	1.795	.297	7.54
Total	4,007- 0 in.	2,450	1.636*	$0.305*	$ 8.25*

	Cu. Ft.	Cu. Yd.
Average cost Abutment Steps and Bridge Seats..	$0.262	$7.08
Average cost Pier Coping......................	0.366	9.89

*Average.

Concrete.—The concrete was deposited under water in the open cofferdams, a 2 cu. yd. bucket, which dumped as it struck the bottom, being used for this purpose. The concrete was mixed in the proportion of 1 : 2 : 4, gravel being used in place of broken stone. Portland cements—Victor, Ironclad and Navarite brands—

TABLE XVII.—CLEANING AND REPAIRING FOR CONCRETING.

		Number of Hours.					Cost of Labor.					No. of Hrs. per Cu. Yd. Concrete, Average.	Cost per Cu. Yd. Concrete, Average.
	Rate.	Abut. No. 1	Pier No. 2	Pier No. 3	Pier No. 4	Total.	Abut. No. 1	Pier No. 2	Pier No. 3	Pier No. 4	Total.		
Superintendent	70	....	4	64	....	68	......	$ 2.80	$ 44.80	......	$ 47.60	0.03	$0.02
Drivers	50	230	120	220	20	590	$115.00	60.00	110.00	10.00	295.00	.27	.014
Carpenters	20	....	....	10	....	10	......	......	2.00	......	2.00	.005	....
Enginemen	30	40	....	22	....	62	12.00	......	6.60	......	18.60	.03	.01
Laborers	20	1,020	480	554	80	2,134	204.00	96.00	110.80	16.00	426.80	.97	.19
Timekeeper	40	....	3	....	....	3	......	1.20	......	......	1.20	.001	....
Total							$331.00	$160.00	$274.20	$26.00	$791.20	....	$0.36

CONCRETING.

Workmen.		Number of Hours.					Cost of Labor.					Cost per Cubic Yard.				
	Rate.	Abut. No. 1	Pier No. 2	Pier No. 3	Pier No. 4	Total.	Abut. No. 1	Pier No. 2	Pier No. 3	Pier No. 4	Total.	Abut. No. 1	Pier No. 2	Pier No. 3	Pier No. 4	Average.
Superintendent	70	24	47	72	16	159	$16.80	$32.90	$50.40	$11.20	$111.30	$0.03	$0.09	$0.05	$0.03	$0.05
Foreman	35	160	128	324	54	666	56.00	44.80	113.40	18.90	233.10	.09	.13	.12	.06	.11
Laborers	15 / 20	2,555	2,038	3,513	940	0,0[illegible]6	383.25	313.60	526.95	141.00	1,364.90	.65	.92	.56	.44	.62
Enginemen	30	365	196	244	60	865	109.50	58.50	73.20	18.00	259.50	.19	.17	.08	.06	.12
Timekeeper	40	86	46	81	10	223	34.40	18.40	32.40	4.00	89.20	.06	.05	.04	.01	.04
Total							$599.95	$468.50	$796.35	$193.10	$2,057.90	$1.02	$1.36	$0.85	$0.60	0.94

SUMMARY.

	Depths in Feet.	Begun 1899.	Finished 1899.	Cu. Yds. Concrete.
Abutment No. 1	18	Oct. 2	Oct. 19	587.63
Pier No. 2	30	Aug. 21	Oct. 3	344.72
Pier No. 3	34	Aug. 28	Aug. 30	324.01
Pier No. 4	30	July 31	Aug. 9	942.62

were used. The mixing was done by a rectangular horizontal machine mixer. The concrete was deposited continuously, working day and night, except in the case of pier No. 2, where an accident to the cofferdam sides caused an interval of several weeks.

Table XVII of costs for cleaning and repairing is for the work of. the diver in removing with hoes, shovels and pumps the silt which had been deposited on the foundation site. The foundations had been cleaned by the dredge several months before, the work of the diver being to remove the silt which had afterwards been deposited. There was much soft material in abutment No. 1, owing to the proximity of the embankment. At pier No. 3 the cofferdam rested upon a rock, which had to be drilled and blasted. Little work was required at pier No. 4, as the site was comparatively clean. In the table for concreting, the high cost of the work on pier No. 2 was due to the fact that the concrete was improperly deposited and had to be removed. In the same table, the higher cost for the work under abutment No. 1, was probably due to the fact that the abutment was so long and narrow that it was difficult to handle the bucket.

Weight and Cost of the Washington Bridge, N. Y. City.*—In his book entitled "The Washington Bridge," Mr. William R. Hutton gives the following data:

The Washington bridge, across the Harlem River, was built in 1886-1888 by contract. It consists of two steel arch spans of 510 ft. each, and six masonry arch approach spans of 60 ft. each. The width of the carriage way is 50 ft., and each of the two sidewalks is 15 ft. wide. The rise of the steel arches is 92 ft., the spring line being 41 ft. above M. H. W. The center pier rests on a caisson sunk 40 ft. below M. H. W. The other two main piers required no caisson work. The masonry of these three main piers was carried up to the floor level of the bridge. The main piers are 40 ft. thick at the spring line and 98 ft. long. They are of concrete, faced with granite. Above the stone back they are cellular. The total length of the bridge between abutments is 1,550 ft. In addition to this there are approaches, consisting of embankments supported by retaining walls, at each end of the bridge.

The two steel arches required 1,500,000 ft. B. M. timber for the falsework (one span rested on piles), and the six masonry arches required 1,500,000 ft. B. M., including timber used in trestles for landing materials. Each of the steel arches consists of 6 steel ribs of 13 ft. deep.

The superstructure of each 510 ft. long weighs 13,086 lbs. per ft. of span, and is designed for a live load of 8,000 lbs. per ft. of span. The cost of this bridge was:

Paid to contractors	$2,648,785
Engineering, etc.	162,400
Commissioners' office	40,500
Total	$2,851,685

*Engineering-Contracting, July 14, 1909.

This is equivalent to $23 per sq. ft. of roadway between the abutments. Some of the principal quantities and cost were as follows:

8,358	cu. yds. granite in piers (dressed)	$203,101
2,300	cu. yds. cornice and parapet	201,245
15,491	cu. yds. arch voussoirs	248,393
16,545	cu. yds. facing	174,762
29,348	cu. yds. granite concrete	161,052
31,219	cu. yds. earth excavation	80,048
26,504	cu. yds. rock	29,211
12,815	cu. yds. embankment	7,538
4,052	cu. yds. caisscn	182,354
151,078	sq. ft. flagging (sidewalk)	49,577
13,742	sq. yds. asphalt roadway	62,782
7,549,606	lbs. steel in arch ribs and bracing	777,359
5,927,816	lbs. iron in posts, bracing and floor	777,359
1,233,874	lbs. cast and wet iron in cornice and balustrade	132,260

The caisson foundation of the center pier contained 7,726 cu. yds. of timber and concrete for the 40½ ft. below the highwater line, which cost the city $30.64 per cu. yd.

The contractor paid the following wages: Laborers, $1.75; masons and stone cutters, $3.50; drillers, $2; enginemen, $2.50; carpenters, $3; painters, $1.75.

Portland cement was substituted for Rosendale for about 40 per cent of the amount of cement used, adding $32,000 to the cost above given.

Cost of a Bridge Foundation Excavation and Cofferdam.—Mr. Walter N. Frickstad gives the following data on bridge foundation work, done by force account, by the Southern Pacific R. R. in Nevada, year 1902-3. In crossing the Humboldt River the line made a very sharp angle with the river, but a skew bridge was not used. There were two abutments and one pier. To build the east abutment an *L*-shaped cofferdam of sand bags, filled in between with earth, was used. The long leg of the *L* was 100 ft. long, and the short leg 40 ft. long. This enclosed a triangle of water, bounded by the two legs of the *L*-shaped cofferdam and the shore line of the river. The sand filled sacks were wheeled to place and deposited by men provided with long-handled shovels and sticks to guide them to place; but it was not found practicable to build the sacks up in tiers, for the air spaces in the sacks buoyed them so that they were easily displaced by the river current. It was intended to leave a 3-ft. space between two tiers of sacks, to be filled with puddle, but this space became choked with sacks. It was found impossible to pump out this dam with a one-man sewer "deluge" pump, so a bank of earth was deposited outside of the dam of sacks. Where the current was swiftest, the earth was rushed to place with a steady stream of wheelbarrows, the coarsest gravel being used as a riprap on the loam and sand; and, in spite of current of 5 ft. per second, the embankment held its place. Then with 4 men on a shift, two working while two rested alternately in 15-minute periods, the dam was pumped dry in 2 days and 3 nights, at a cost of $19 per 24 hrs. To reduce the area, to be kept pumped out, a cross-wall of sacks, 30 ft. long, was put in. About 2,230 sacks were used, all told.

This work cost as follows:

Building L-shaped dam, 53 days, at $1.50	$ 79.50
Filling its slope with earth, 32 days, at $1.50	48.00
Building cross-wall of dam, 30 days, at $1.50	45.00
Excavating mud and loose rock, 24 days, at $1.50	36.00
Pumping until masons were above water line, 85 days, at $1.50	127.50
Foreman, 9 days, at $3	27.00
Total	$363.00

While the masons were at work on the east abutment the coffer dam of the center pier was built in a manner that proved to be the cheapest and requiring the least equipment of all the methods of cofferdamming used. To get to bed rock there were 2 ft. of silt, 7 ft. of gravel and boulders and 5 ft. of boulders. Tests with long drills had led the engineers to believe that solid rock was 5 ft. nearer the surface, the boulders being mistaken for solid rock. The pier was of masonry with a sharp nose at each end, so the cofferdam was made of similar shape and with a length of 55 ft.

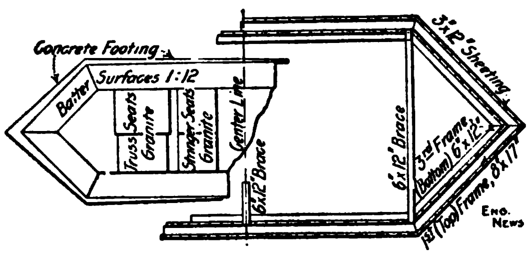


Fig. 9.—Plan of Cofferdam.

from nose to nose, and an outside width of 16 ft. The cofferdam consisted of sheet piling driven by hand as fast as the excavation progressed inside, just as in ordinary sheeting of a sewer trench. The rangers, or waling pieces, to support the sheet piling were made of 8 x 17-in. Oregon pine, drift-bolted together to form a frame, as shown in Fig. 9. This frame was laid flat just above the surface of the water, being temporarily supported by a bar of river sand at one end and by a pair of wooden horses (4 ft. high) near the other end. These horses were built and sunk in the stream, and planks laid out from the sand bar, upon which to push the frame to place on 1¼-in. gas pipe rollers by four men using pinch bars. About one-third of the frame overhung these horses, and the water was 7 ft. deep at the outer nose of the frame. Holes were dug 2 ft. deep under the three corners of the frame that rested on the sand bar, and temporary posts set in these holes to support that end of the frame. Then excavation was begun, 8-ft. lengths of sheet planking or piling being driven, starting at the nose of the frame. A heavy wooden maul was used to drive the sheeting. When 12 of these 3 x 12-in. sheeting planks had been driven down a short distance, earth and manure were piled outside. Then the lines of sheeting were continued out into the river,

using longer plank. Finally several of the sheeting planks were temporarily spiked to the frame, the horses removed, and plank driven to close the gaps. Earth and manure were banked up outside the sheeting. It was found necessary to deflect the river current, which was washing away this earth and manure, and to do this a wing dam of sacks filled with sand was built, and coarse gravel and sand-filled sacks used to riprap the outer end of the earth and manure fill. The water was readily pumped out, and excavation begun. It was found that the sheeting was sloping inward, so a second frame was built of 6 x 12's inside the excavation and at the bottom of the sheeting; then the driving of the sheeting was continued and this second frame was lowered as the excavation progressed. Once the gravel caved and two sheet planks were forced in, but quick work with brush, manure and earth

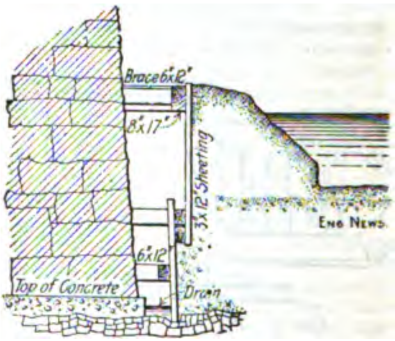


Fig. 10.—Section of Cofferdam.

closed the hole. When the excavation was 7 ft. below the water surface, and rock was not encountered, it was decided to build a third frame and drive a second tier of sheet plank inside, and sloping outward, as in Fig. 10. This was begun when the flow of water became so great that a 6-hp. Fairbanks, Morse & Co. combined gasoline engine and pump was installed, and no further difficulty occurred in getting down to bed rock. The cost of this pier excavation by force account was as follows:

Labor excavating, etc., 324 days, at $1.50	$ 486.00
Labor pumping, 136 days, at $1.50	204.00
Engine-runners, 50 days, at $3	150.00
Four-horse team, 6 days, at $6	36.00
Carpenter, 8 days, at $3	24.00
Foreman, 24 days, at $4	96.00
115 gallons gasoline, at 15 cts.	17.25
300 sacks, at 15 cts.	45.00
10 M. of pine, at $30	300.00
Total	$1,358.25
Salvage value of 5 M of pine removed	150.00
Total for 280 cu. yds. excavation, at $4.30	$1,208.25

I have assumed the prices and rates of wages as above given, although in fact they may have varied slightly. The number of days' work and the amount of materials is exact. It will be noted that half the timber in the cofferdam was recovered and used elsewhere. The cost of excavation was high, because no derricks were used, but the shoveling was done in stages; moreover, there was a large quantity of boulders, and trouble with pumps caused considerable delay.

The excavation for the west abutment, though much larger than for the pier just described, was done in the same manner. The cofferdam inclosed an *L*-shaped area, about 60 ft. long on each leg of the *L*, and about 20 ft. wide. The waling frames were built in place after the site had been excavated to the water level with drag scrapers, and the second and third frames in due course. In lowering the frames from time to time as the excavation progressed, it was found almost impossible to drive them down with a 16-lb. sledge or a wooden maul. Even a 6-in. x 12-in. x 8-ft. wooden rammer, operated by two men, failed to drive the frames. It was found that by loading the shoveling platforms, 2 ft. wide by 16 ft. long, with gravel, one platform being loaded on each side the section to be lowered, a slight tapping produced any desired amount of settling. The excavation was not carried to bed rock, but the abutment was founded on the gravel and boulders, at a depth of 12 ft. below the water surface. The cost of this work was as follows:

Team on drag-scraper, 18 days, at $3.50	$ 63.00
Laborers, 748 days, at $1.50	1,122.00
Carpenter, 35 days, at $3.00	105.00
Pump engineers, 140 days, at $3.00	420.00
Foreman, 35 days, at $4.00	140.00
45 tons coal, at $6.00	270.00
150 gallons gasoline, at 15 cts	225.00
22 M lumber, at $30	660.00
Total	$3,005.00
Salvage value of 11 M lumber removed	330.00
Total, 700 cu. yds., at $3.82	$2,675.00

Cost of Coffer Dam.*—Maj. Graham D. Fitch gives the following: A cofferdam was built on the Upper White River, Arkansas, within which to build a lock. Common laborers received $1.50 per 8-hr. day. The work was done by Government forces.

The lock (No. 1) was founded on sandstone bed rock, and as the foundation bed afforded no foothold for piles, crib cofferdams were used. These were built and sunk in sections from 20 to 30 ft. long, each section consisting of round oak logs 7 to 9 ins. in diameter, driftbolted together with ⅝-in. round iron. The walls were tied together every 10 ft. by a transverse crib wall. Above the water the cofferdam was a continuous crib. The inside faces of both walls were sheeted with boards driven to a good bearing with hand mauls, a single row of 1-in. boards being used for the outer wall and double lap 1-in. and 2-in. boards for the inner wall,

**Engineering-Contracting,* May 6, 1908, p. 278.

The pens were filled with clay and the dam well banked on the outside. The puddle, which was taken from a bank nearby, was loaded by a dipper dredge on a barge and placed in the dam with shovels. The inside width of the cofferdam was 10 ft. 8 ins., and its length was 462 ft. It was built to a 9 ft. stage and had an average height of 17 ft. The dam was built in 6 weeks time and the pit was pumped out in about 11 hours with one 10-in. centrifugal pump. A 3½-in. pulsometer pump was used to keep seep water out of the pit. There was very little leakage except during rises, after which the dam always had to be repuddled, as much of the backing was washed away by the swift current. The cost of this cofferdam was as follows:

COFFERDAM (462 LIN. FT.).

Materials:	Unit Cost.	Total.	Per lin. ft. Cofferdam.
Logs, 30,560 lin. ft.	$ .0365	$1,115	$2.41
Timber, 32.8 M ft. B. M.	10.90	360	.78
Iron, 8,139 lbs.	.0289	234	.51
Straw, 12 loads	1.75	21	.04
Fuel	....	177	.38
Illumination, oils, etc.	....	104	.22
Total materials		$2,011	$4.34
Labor:			
Quarrying and placing breakwater stone, 498 cu. yds.	$ 0.718	$ 388	$ .85
Excavation, 300 cu. yds.	.562	169	.36
Hauling lumber, 20 M ft.	.86	17	.04
Placing logs, 30,560 lin. ft.	.02	638	1.38
Placing timber, 32.8 M ft.	1.73	57	.12
Digging puddle, 7,860 cu. yds.	.062	490	1.06
Placing puddle, 7,860 cu. yds.	.53	4,179	9.05
Pumping pit	....	539	1.17
Total		$6,476	$14.03
Grand total		$8,487	$18.37

Some of the labor items may be still further summarized as follows:

	Work done.	Labor time in days.	Work done per man per day.
Quarrying and placing breakwater stone	498 cu. yds.	248	2 cu. yds.
Excavation	300 cu. yds.	95 1/8	3.16 cu. yds.
Placing logs	30,560 lin. ft.	370 1/8	82.59 lin. ft.
Placing timber	32.8 M ft.	37 4/8	.863 M ft.
Placing puddle	7,860 cu. yds.	2,392 6/8	3,284 cu. yds.

The total labor time in constructing the 462 lin. ft. of cofferdam was 3,660⅛ days. The unit cost per linear foot of cofferdam was $18.37 and the work done per man per day was .126 lin. ft. About 90 lin. ft. of cofferdam was removed by dredge and men, at a cost of $161; the labor time being 86⅝ days. The unit cost was $1.794 per lin. ft.

In excavating for the foundation of the lock a 1¼ cu. yd. Bucyrus dipper dredge removed from the pit, before the cofferdam was closed, such material as it could handle; but owing to the large boulders encountered most of the excavating was done by hand after the cofferdam had been pumped out, the material—clay, boulders, and cemented gravel—being removed by wheelbarrows and derrick skips. The lockwall foundations averaged 6 ft. in depth below the lock floor, the maximum depth being 6 ft. 5 ins. Both the chamber and miter wall were founded on bed rock.

The cost of excavation work was as follows:

EXCAVATION (3,635 CU. YDS.).

	Unit Cost.	Total.	Per cu. yd. Excavation.
Material:			
Dynamite, 600 lbs.	$0.14	$ 84	$0.023
Fuel	....	9	.002
Illuminating oils, etc.	....	119	.032
Total materials		$ 212	$0.057
Labor:			
Excavating, 3,365 cu. yds.	$1.49	$5,438	$1.49
Cleaning lock pit	....	108	.029
Total labor		$5,546	$1.519
Grand total		$5,758	$1.58

The total labor time in days for excavating was 3,138¼ days and the work done per man per day was 1.16 cu. yds.

Cost of Placing Puddle in a Coffer Dam by Pumping.*—Mr. William Martin is authority for the following data:

In building Davis Island Dam, several years ago, a cofferdam 1,085 ft. long, containing 5,784 cu. yds. of puddle material, was built by pumping the puddle from an island. The cofferdam consisted of two rows of piles, the rows being 15½ ft. c. to c. and the piles in each row being 21 ft. c. to c. The piles were 20 ft. long, and were driven 8 ft. Three rows of wale pieces or stringers were bolted to the piles, 12 ft. apart. A single line of vertical sheeting plank, driven 2 ft. into the gravel bottom, rested against the wales. The joints of the sheeting were covered with 1x6 in. strips to prevent leakage of the puddle. On each side of the sheeting, at the top, was spiked a 2 x 10 in. string piece, to form a bearing upon which a plank deck was laid.

The plant, as finally developed, was as follows:

Tubular boiler, 36 ins. diam. x 16 ft. long.

Engine, 10 x 10 ins.

Piston pump—steam cyl. 12 x 18 ins.; water cyl. 6½ x 18 ins.

Centrifugal pump, 3 in. discharges.

Pipes, etc., of the following sizes were used: Delivery pipe, 4-in.; clearing pipe, 2½-in.; priming pipe, 1½-in.; lubricator pipe, 1-in.; steam pipe to engine, 2½-in.; steam pipe to piston pump, 2-in.; band wheel on engine shaft, 4½ ft.; pulley on centrifugal pump shaft, 10 ins.; width of driving belt, 10 ins.; agitator hose, 1½ ins.

*_Engineering-Contracting_, Jan. 6, 1909.

The following pressures were obtained: Steam boiler, 100 lbs. per sq. in.; gage on piston pump, 70 lbs.; gage on delivery pipe, 35 lbs.

The centrifugal pump for pumping the puddle was located on an island 900 ft. from the cofferdam. Beneath the pump was a tank for mixing the puddle, 8 ft. diameter and 4 ft. deep, sunk to a sufficient depth to secure a fall of water from a flume that tapped the river.

The piston pump was connected to the delivery pipe by a wye connection, and was used for priming the centrifugal pump, and keeping the sand from packing, and for furnishing water for the steam boiler and for the agitator hose, as hereafter described.

The puddle, consisting of loam and sand, was obtained within a radius of 100 ft. from the pump by loosening with a plow and delivering close to the tank with drag scrapers. It was then shoveled by hand into the tank, a cost that could have been avoided had the scrapers dumped through a trap into the tank. The material was mixed with water in the tank and kept agitated by water from a hose in the hands of workmen, to prevent the earth from settling to the bottom. This puddle was taken by the feed pipe of the centrifugal pump and forced through the delivery pipe to the cofferdam, a distance constantly increasing as the work progressed. The delivery pipe was laid on the bottom of the river, and then rose by an easy ascent to about 1 ft. above the top of the cofferdam.

The puddle occasionally became so thick as to clog the delivery pipe. In order to meet this difficulty, the following ingenious plan was devised. On the delivery pipe at the centrifugal pump was placed a pressure gage. Any clogging of the delivery pipe immediately caused the pressure to rise, whereupon the engineman slackened the speed of the centrifugal and opened the valve in the wye connection to the piston pump. This admitted a stream of clear water at high pressure from the piston pump and immediately cleared the congestion of puddle in the delivery pipe. The check valve in the delivery pipe between the wye connection and the centrifugal pump prevented a back flow into the centrifugal pump.

At the bottom of the feed pipe in the tank was a screen having 1-in. meshes. Above the screen, and in the same casing, was placed a foot valve for the purpose of holding the priming.

One of the principal difficulties in working the centrifugal pump was the rapid wear of all its parts that came in contact with the sand. The casing, which was originally ⅝-in. thick, wore through in 10 days, during which time not 2,500 cu. yds. of puddle were handled. This was replaced with a 1-in. casing which was still in service after the 13 days use which completed the job.

The stuffing box wore rapidly until the following ingenious device was applied: A screw was cut in the chamber in the opposite direction to the motion of the shaft. A pipe was put in back of the packing and connected with the piston pump. Water was forced through this around the shaft, and, being under a greater pressure than the centrifugal pump, prevented the puddle material from getting into the stuffing box. Water thus applied performed a

double duty, for it acted as a lubrication and prevented the shaft from heating.

At the discharge end of the delivery pipe the puddle material was deposited in the cofferdam and flowed off for a distance of a few hundred feet, depositing in a hard and solid mass. The loam being lighter, remained longer in suspension and settled out on top of the sand.

In 23 days there were delivered 5,784 cu. yds. of puddle material, or 251 cu. yds. per 10-hr. day. Laborers received $1.75 to $2 a day, and mechanics $2.50 to $2.75. The cost was as follows:

Plant:	
Pump	$ 145
Repairs, fittings, etc.	382
Pipe	364
Total cost of plant	$ 891
Labor:	
Installing plant and pumping puddle, removing plant, etc.	$2,847
Fuel:	
23 days fuel	$ 38
Total labor and fuel	$2,885

It will thus be seen that the cost of labor and fuel for puddling amounted to $265 per lin. ft. of cofferdam, or 50 cts. per cu. yd., including the labor cost of installing the plant. It is unfortunate that this item of installation and removal of plant was not kept separate, as it was evidently a large item. The fuel cost only $1.65 a day, or ⅔ ct. per cu. yd. The labor during the 23 days of pumping could probably not have exceeded 4 cts. per cu. yd. for pumping and pipe laying. With a haul averaging about 50 or 60 ft. for the drag scrapers, the cost of delivering the puddle alongside the tank probably did not exceed 10 cts. per cu. yd. Shoveling it into the tank doubtless cost less than 10 cts. per cu. yd. This would make a total of not more than 25 cts. per cu. yd. for the puddle in place, exclusive of plant charges for interest, depreciation, repairs and installation. Apparently the installation and removal of the pumping plant cost at least $1,500. The plant itself cost $891, as above given. The exceptionally high cost of installation appears to have been due in part to the experimenting incident to developing the best way of handling the material, most of which cost can be saved by studying the finally adopted methods and devices above given.

For comparative purposes it is well to add the following costs of filling another section of another cofferdam nearby by another method. The other section was 1,165 ft. long, and it cost $5.69 per lin. ft. for puddle in place, or practically $1.10 per cu. yd. of puddle. The method employed consisted in loading the material by hand into cars, hauling it over a narrow gage track to the river, loading into boats and transporting to the cofferdam, shoveling by hand into place, and compacting with water. Wages were only $1.25 a day for laborers, and $2.25 for mechanics.

The Cost of Some Masonry Bridge Piers and Abutments.*—Some fairly complete data as to the cost of constructing bridge masonry are given below. The work, which was done by contract for the Chicago & West Michigan Ry., consisted of the construction of a pier and abutment at New Buffalo, Ind., to carry the tracks of the above road over the Michigan Central R. R. Work was commenced Aug. 24, 1891, and was finished Oct. 27, 1891, taking in all 56 working days.

The average working force and its wages per day were as follows:

1 Foreman	$2.50
1 Engineman	2.00
4 Stonecutters	3.00
1 Mason	2.50
9 Laborers	1.50

From this it will be seen that the total labor cost per day was $32.50, and the total cost for 56 days was $1,525.

The cost of the labor was distributed as follows:

	Cu. yds.	Cost.	Cost per cu. yd.
Excavating, abutment	868	$183	$0.153
Excavating pier	232	45	0.194
Cutting stone, abutment	281	514	1.93
Cutting stone, pier	163	347	2.13
Setting stone, abutment	281	197	0.70
Setting stone, pier	163	152	0.93
Unloading stone from cars	444	50	0.11

To the above should be added $86.50 as the cost of erecting and moving the plant.

The total cost of the work to the contractor amounted to $1,863, as is shown by the following figures:

Labor	$1,525.00
78 bbls. Louisville and Miller cement	78.00
8 bbls. Buckeye cement	30.00
40 yds. sand	30.00
10% of value of plant	200.00
Total	$1,863.00

According to the estimate on which the contractor was paid he was to receive $6.50 per cu. yd. for masonry cut and placed, and $0.25 per cu. yd. for excavation. As 444 cu. yds. of masonry were constructed and 1,100 cu. yds. of earth excavated, the contractor received $3,148.50. His total expenses, as shown in the preceding paragraphs, were $1,863; therefore he made a profit of $1,285.50 on the job.

The total cost of the Chicago & West Michigan Ry. was $5,884.65; this includes the estimate of $3,148.50 and the furnishing of 435 cu. yds. of stone, costing $6.29 per cu. yd.

The stone used was Grafton sandstone delivered on cars at La Porte, Ind. It should also be added that the amount given for

*Engineering-Contracting, May 30, 1906.

use of plant covered the expense of repairng stonecutters' tools and the cost of fuel.

Cost of a Masonry Bridge Abutment.*—We give herewith the cost of constructing the west abutment of a 60-ft. through girder bridge near Ionia, Mich., where the Detroit, Lansing & Northern R. R. crosses Prison Road. The work was done by contract for the above-mentioned railroad. According to the terms of the contract the railroad company furnished the stone and free transportation of men and materials; the contractor furnished all other material and labor, and in addition was paid for all timber left in the construction. His plant consisted of a steam hoist derrick with accompanying tools, etc. The stone used was sandstone from Grafton, O., and was delivered f. o. b. Detroit. The average weight of a carload of stone was 33,873 lbs., and the average carload contained 203 cu. ft. The average weight per cubic foot, according to car weights and quarry measurements, was 166.8 lbs. Hanover Portland cement was used, and on account of the low temperature when the work was done, it was necessary to add salt to the mortar. In the excavation, the removal of excavated matter was done almost entirely with wheelbarrows. The excavated material was sand and was wasted. The overhaul was only a short distance, the lead being but 75 ft. The work of excavating was commenced November 18, 1893, the first stone was laid December 5, and the last stone January 7, 1894; two days later the contractor finished removing his plant. As will be seen from the above dates, the work was done in the winter, and this accounts in a measure for the higher cost of stonecutting, etc. Indeed, it was necessary to use heated sand to remove the frost from the stone before it was cut.

The tables below give the actual cost of materials and labor to the contractor:

MATERIALS.

34½ bbls. Hanover Portland cement at $2.85	$ 98.32
24 wagon loads sand at $0.75	18.00
2 bbls. salt at $1.00	2.00
Coal for engine	20.00
2 cords wood (heating sand)	3.50
Total	$141.83

LABOR.

Erecting and Removing Plant.

Foreman	2.2	days at	$3.00	$ 6.60
Foreman	4.2	" "	1.75	7.35
Laborers	29.7	" "	1.50	44.55
Engineman	2.2	" "	1.75	3.85
Derrickman	2.2	" "	1.50	3.30
Total labor cost				$65.65

**Engineering-Contracting*, May 30, 1906.

Excavation.

Foreman	8.9 days at $1.75		$15.58
Laborers	64.8 " " 1.50		97.20
Engineman	0.4 " " 1.75		.70
Derrickman	0.4 " " 1.50		.60
Total, 772 cu. yds. at $0.15			$114.08

Unloading Stone.

Foreman	0.6 days at $3.00		$1.80
Foreman	1.1 " " 1.75		1.93
Laborers	3.7 " " 1.50		5.55
Engineman	1.1 " " 1.75		1.93
Derrickman	1.1 " " 1.50		1.65
Stonecutter	1.3 " " 3.00		3.90
Total, 165.6 cu. yds. at $0.10			$16.76

Stonecutting.

Stonecutters	141.4 days at $3.00		$424.20
Scabblers	11.1 " " 1.50		16.65
Engineman	9. " " 1.75		15.75
Derrickman	9. " " 1.50		13.50
Labor heating sand	9.4 " " 1.50		14.10
Blacksmith	15. " " 1.75		26.25
Total, 181.2 cu. yds. at $2.81			$510.45

Setting Stone in Abutment.

Foreman	7.4 days at $3.00		$22.20
Foreman	9.6 " " 1.75		16.80
Mason	2.5 " " 3.00		7.50
Laborers	38.6 " " 1.50		57.90
Engineman	5.7 " " 1.75		9.98
Derrickman	5.7 " " 1.50		8.55
Total, 181.7 cu. yds. at $0.68			$122.93

Laying Stone in Retaining Wall.

Foreman	1.4 days at $1.75		$2.45
Laborers	5. " " 1.50		7.50
Engineman	0.5 " " 1.75		.88
Derrickman	0.5 " " 1.50		.75
Total, 16 cu. yds. at $0.72			$11.58

Old Masonry of West Abutment Taken Down.

Foreman	1 day at $1.75		$1.75
Laborers	6 " " 1.50		9.00
Total, 30.5 cu. yds. at $0.35			$10.75

Preparing East Abutment for Bridge Seat.

Foreman	1.2 days at $1.75		$2.10
Laborers	4. " " 1.50		6.00
Total			$8.10

Pointing.

Foreman	.8 day at $3.00		$2.40
Laborers	2.3 " " 1.50		3.45
Total			5.85

Backfilling.

Foreman	2.4 days at	$3.00	$ 6.80
Foreman	6.3 " "	1.75	11.03
Laborers	37.8 " "	1.50	56.70
Engineman	3.6 " "	1.75	6.30
Derrickman	3.6 " "	1.50	5.40
Total, 380 cu. yds. at $0.23			$86.23

The total labor cost to the contractor was $952.38, to this must be added $120.00 for depreciation and repairs to plant, and $141.83 for the cost of materials, thus making the total cost to the contractor for material and labor amount to $1,214.21.

The final estimate of work done by the contractor and the unit rate at which he was paid for it, were as follows:

772 cu. yds. excavation at	$0.25
380 cu. yds. backfilling at	0.25
181.7 cu. yds. masonry, cut and place at	6.15
16 cu. yds. masonry (retaining wall) at	4.00
30.5 cu. yds. old masonry taken down at	0.30

Total paid to contractor, $1,478.73.

As was shown in the preceding paragraph the total actual cost of the work to the contractor was $1,214.21. His profit accordingly amounted to $264.52 or 21.8 per cent.

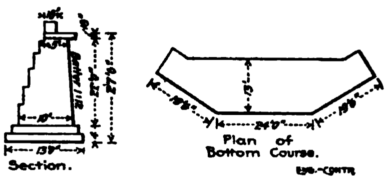


Fig. 11.

The cost to the Detroit, Lansing & Northern R. R. was as follows:

165.6 cu. yds. Grafton standstone at $6.021, $997.22; amount paid contractor, $1,478.73; total, $2,475.95.

The cost per cubic yard of masonry to the railroad company was as follows:

181.72 cu. yds. of stone (wall measurement), total cost, $997.22; per cubic yard, $5.48; 181.72 cu. yds. of stone cut and placed, cost $6.15 per cu. yd.; total cost per cubic yard of masonry is therefore $11.637.

Labor Cost of a Bridge Abutment.*—The work was done by contract during the fall of 1893 for the Detroit, Lansing & Northern R. R., near Redford, Mich. Figure 11 shows plan of the abutment. According to the terms of the contract, the railroad company furnished the stone and free transportation of men and materials, and the contractor furnished all other material and labor, and in addi-

**Engineering-Contracting,* June 6, 1906.

tion was paid for all timber left in the construction. The stone used was sandstone from Grafton, O., delivered f. o. b. Detroit, Mich. The average weight of the stone per carload was 41,900 lbs.; the average number of cubic feet per carload was 240. The average weight of a cubic foot of the stone as amputated from the car weights and quarry measurements was 174.4 lbs. It should be noted, however, that the true dimensions of the stone were considerably larger than the quarry measurements, and this accounts for the apparent large weight per cubic foot.

Buffalo natural cement was used in the greater part of the work, but Dyckerhoff Portland cement was used for pointing and for joints in the face of the work as far as 10 in. back from the face. The sand was obtained from the property of the railroad company, the only cost to the contractor being for the loading and unloading. The material excavated was sand and clay, and was removed from the excavation by wheelbarrows and by boxes holding about 1½ cu. yds., which were lifted out by the derrick. The greater part of the excavated material was removed by the latter method.

The contractor's plant consisted of a steam hoist derrick and a hand derrick. For driving the sheet piling a small man-power driver was constructed. This was built with an oak driver weighing 125 lbs., and having a drop of about 4 ft. The sheet piling was double and triple 1 in. x 12 in. oak, 10 ft. long, and was driven 8 ft. through clay and coarse gravel. The contractor began erecting his plant September 7, 1893. On September 11 excavation was started, and October 2 the first stone was laid; the last stone was laid November 19, and one week later the contractor finished removing his plant.

LABOR.

Erecting and Removing Plant.

Foreman	5.5 days at $2.50	$13.75
Laborers	55.4 " " 1.50	83.10
Engineman	1.8 " " 1.75	3.15
Total		$100.00

Earth Excavation, Wet and Dry.

Foreman	12.9 days at $2.50	$ 32.25
Laborers	197.8 " " 1.50	269.70
Engineman	9.8 " " 1.75	17.15
Derrickman	8.2 " " 1.50	12.30
Water boy..............	9.9 " " 0.75	7.43
Total, 1,632 cu. yds. at $0.21............		$338.83

Pumping Water.

Laborer	6.3 days at $1.50	$9.45

Making Sheet Pile Driver.

Foreman	0.8 days at $2.50	$2.00
Laborers	3.5 " " 1.50	5.25
Water boy	0.15 " " 0.75	.11
Total		$7.36

Driving Sheet Piling.

Foreman	4.4 days	at $2.50	$11.00
Laborers	165.2 "	" 1.50	247.80
Water boy	9.6 "	" 0.75	7.20
Total, 8,932 ft. B. M. at $2.98			$266.00

There were 2,227 lin. ft. of sheet piling, so that the labor cost was 12 cts. per ft.

Concrete.

Foreman	5.7 days	at $2.50	$14.25
Laborers	42 "	" 1.50	63.00
Engineman	1.25 "	" 1.75	2.19
Derrickman	7.9 "	" 1.50	11.85
Water boy	2 "	" 0.75	1.50
Total, 57 cu. yds. at $1.63			$92.79

Unloading Stone from Cars.

Foreman	3.65 days	at $2.50	$ 9.13
Laborers	30.3 "	" 1.50	45.45
Engineman	3.6 "	" 1.75	6.30
Derrickman	3.6 "	" 1.50	5.40
Stonecutters	14.7 "	" 3.00	44.10
Total, 657½ cu. yds. at $0.17			$110.38

Stonecutting.

Engineman	23.8 days	at $1.75	$ 41.65
Darrickman	24.7 "	" 1.50	37.05
Stonecutters	284.9 "	" 3.00	854.70
Scabblers	28.4 "	" 1.50	42.60
Blacksmith	3.3 "	" 1.75	58.28
Water boy	14.7 "	" 0.75	11.03
Total, 657½ cu. yds. at $1.59			$1,045.31

Setting Stone.

Foreman	30.7 days	at $2.50	$ 76.75
Mason	47.4 "	" 1.50	71.10
Laborers	59.3 "	" 1.50	88.95
Engineman	11.4 "	" 1.75	19.95
Derrickman	17.4 "	" 1.50	26.10
Water boy	9 "	" 0.75	6.75
Total, 657½ cu. yds. at $0.44			$289.60

Pointing.

Mason	10 days	at $1.50	$15.00

Loading Sand.

Laborer	11.9 days	at $1.50	$17.85

Backfilling.

Foreman	1 day	at $2.50	$ 2.50
Laborers	103.7 days	at 1.50	155.55
Engineman	6.5 "	" 1.75	11.38
Derrickmen	14.5 "	" 1.50	21.75
Water boy	5.3 "	" 0.75	3.98
Total, 796 cu. yds. at $0.245			$195.16

Ditching.

Laborers	2.5 days	at $1.50	$3.75
Total, 27.2 cu. yds. at $0.14			$3.75

Tear Down Old Abutment and Load.

Foreman	4.3 days	at $2.50	$10.75
Laborers	33.2 "	" 1.50	49.80
Total, 90.4 cu. yds. at $0.67			$60.55

Of the 1,632 cu. yds. of earth excavation there were 1,260 cu. yds. dry, and 372 cu. yds. wet. The dry excavation cost $253.08, or 20.8 cts. per cu. yd. The labor of the wet excavation cost $85.75, or 23 cts. per cu. yd., to which must be added nearly 3 cts. for pumping and 73 cts. for the labor of driving the sheet piles, including the labor of making the pile driver. This makes a total of 99 cts. per cu. yd. for the labor of the wet excavation; but in addition to this there was nearly 9,000 ft. B. M. of oak sheet piling, which at $14 per M (a very low price), would add another $180, or nearly 34 cts. per cu. yd., making the total cost nearly $1.33 per cu. yd. for the 372 cu. yds. of wet excavation. Had the sheet piling timber cost $20 per M, the total cost of the wet excavation would have been about $1.50 per cu. yd.

The total labor cost to the contractor was $2,552.03. To this amount must be added the following:

10% value of plant for depreciation and repairs	$140.00
8,932 ft. B. M. oak piling at $14	125.00
215 bbls. Buffalo cement at $0.85	182.75
7½ bbls. Dykerhoff cement at $3.00	22.50
Coal for engine	55.80
Coal for blacksmith	3.40
Total	$389.50
Time work	95.57

The total actual cost to the contractor for labor and materials is accordingly $2,552.03 + $389.50 + $95.57 = $3,177.10. As is shown in the succeeding paragraphs the railroad company paid the contractor $5,377.76 on the final estimate of the work done, thus giving him a profit of $2,200.66.

In the following table is shown the final estimate of the amount of work done by the contractor and the unit rate at which he was paid by the railroad:

1,260 cu. yds. dry excavation at	$0.25
372 cu. yds. wet excavation at	.75
27.2 cu. yds. ditching at	.25
796 cu. yds. back filling at	.25
57 cu. yds. concrete at	3.75
657.5 cu. yds. masonry at	6.15
90.4 cu. yds. old abutment torn down at	1.00
Total	$5,273.63

In addition the contractor was paid for the timber left in the struction and for time labor, the unit costs being as follows:

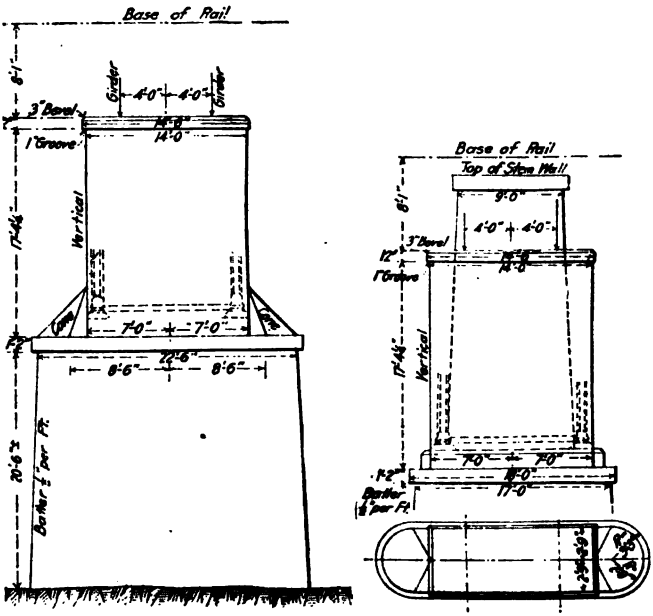
8,932 ft. B. M. oak sheet piling at	$14.00
8 days' labor night watchmen at	1.25
41 days' labor night watchmen at	1.50
2.8 days' labor changing braces at	1.50
13.25 days' labor excavating at	1.50
Total	$95.57

The contractor was paid 10 per cent of this last total, or $9.56, for use of tools, etc., making $5,377.76 as the total amount paid

him on the final estimate. As the railroad company furnished the stone the grand total cost of the work to it was as follows:

600 cu. yds. stone at $5.89	$3,533.05
74.5 cu. yds. broken stone at $1.177	87.71
Amount paid contractor	5,377.76
Total cost of work	$8,998.52

The cost to the railroad company of masonry per cubic yard was as follows: 657.5 cu. yds. stone (laid), cost $3.533.05, $5.37 per cu. yd.; 657.5 cu. yds. stone cut and set, $6.15 per cu. yd. (contract price); total, $11.52 per cu. yd. of abutment masonry.



Plan and Elevation of Piers 2, 3 and 4. Plan and Elevation of Piers 1 and 5

Fig. 12.—Bridge Pier.

Cost of Concrete Foundations for a Railway Bridge.—Mr. J. Guy Huff is authority for the following data. The original Calf Killer River bridge on the Sparta-Bon Air extension of the Nashville, Chattanooga, St. Louis Ry. consisted of two end piers, one middle pier, and a stem wall at each end, carrying Phoenix column deck trusses of the Warren type. The distance from base of rail to bridge seat was 25 ft. 1⅛ ins. In 1905 the old superstructure was replaced by four spans of 75 ft. deck plate girders, two new con-

crete piers being constructed and the old masonry piers built up with concrete. Figures 12 and 13 show arrangement, plans and elevation of the piers.

Briefly described, the method of construction was as follows: The end pieces were built up, the end vertical posts and end braces being encased, the latter being removed when the old structure was taken down; the two new piers were finished complete, the bars of the lower chords of the old bridge being boxed around, and after the old bridge had been removed these slots were filled with concrete; on both sides of the old middle pier falsework towers sufficiently strong to support the ends of the new girders were erected, and after the old spans had been taken down and the new superstructure put in place, the pier was built up.

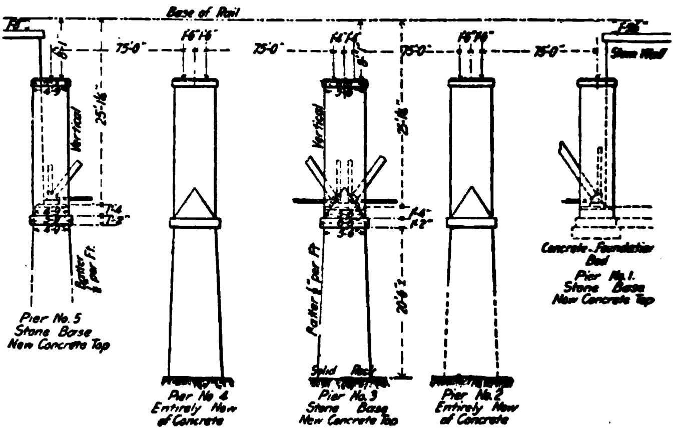


Fig. 13.—Bridge Piers.

The old masonry was built up of concrete to the finish for 7-ft. deck plate girders, using vertical faces and not exceeding the size of the old piers. The length of this top section on the old masonry was 14 ft. on each of the piers, and the design of the new piers was similar in size and shape to the old mid-pier with its new top section.

Mixing and Placing Concrete.—The sand and aggregate, consisting of blast furnace slag obtained from South Pittsburg, Tenn., were unloaded from cars to platforms on a level with the top of rail, placed about 100 ft. south from the south end of the bridge. A cubical form, 1-6 cu. yd. capacity, concrete mixer was used. This was operated by a gasoline engine, and was located on a platform about 50 ft. south of the south end pier. A tank near the mixer to supply water was elevated enough to get the desired head, and was kept filled by a pump run by another gasoline engine located

down by the river bank. The cement house was located between the mixer platform and slag pile.

Slag and sand were delivered to the mixer by means of wheelbarrows. The mixer was so placed that it would dump onto a platform, and the concrete could then be shoveled into a specially designed narrow-gage car. This car ran on one rail of the main track and an extra rail outside. A turnout for clearing passing trains was provided at both ends of the bridge. The track over the bridge from the mixer had a descending grade of about 1 per cent, so that with a little start the concrete car would roll alone down to the required points on the bridge. Only in returning the empty cars to the mixer was it necessary to push it by hand, and then only for a distance of never more than 400 ft.

Over the piers on the bridge in the center of the concrete car's track openings were sawed to let the concrete pass to the forms below. To get the concrete into the forms, there were used zigzag chutes with arms about 10 ft. long, which sections were removed as the concrete in the forms were increased. This chute was a convenience by its end alternating from one side to the other as the arms were removed in coming up.

Cost Data on the Foundation Work.—The foundation work was built by the railway's masonry gangs, the work being commenced about June 20, 1905, and finished complete about Dec. 1 of the same year. The girders were furnished and placed by a bridge company.

In Table XVIII the wages per day are the average rates. The men worked 10 hours each day. The concrete was mixed in a 1 : 3 : 6 proportion.

TABLE XVIII.

Unloading Materials.

	Rate per day.	Total days worked.	Total.	Per cu. yd. Concrete.
Foreman	$3.40	5	$17.00	$0.04
11 laborers	1.36 8/10	52	71.14	.15
Total for unloading material				$0.19

Building Forms, Bins, Etc.

Foreman	$3.40	18	$61.20	$0.14
9 carpenters	2.25	166	373.50	.81
New lumber, 23.7 M ft. at $17.80			421.86	.92
Old lumber, 6 M ft. at $8.33			49.98	.11
Total for building forms, bins, etc				$1.98

Cofferdam Excavation (45 Cu. Yds.)

Foreman	$3.40	8	$27.20	$0.06
9 laborers	1.15 6/10	74½	86 12	.19
Total for cofferdam excavation				$0.25

Cofferdam Concrete (37 Cu. Yds.)

Foreman	$3.40	8	$27.20	$0.06
11 laborers	1.36 3/10	79	107.68	.23
Cofferdam lumber, 2.25 M ft. at $20.00			45.00	.09
Total for cofferdam concrete				$0.38

Concrete Mixing and Placing.

Foreman	$3.40	30	$102.00	$0.22
9 laborers	1.15 6/10	282	325.99	.74
Cement, 452 bbls. at $1.55			701.50	1.52
Slag, 437 cu. yds. at $0.20			87.40	.19
Sand, 220 cu. yds. at $0.30			66.00	.14
Total for mixing and placing				$2.78

Taking Down Forms and Clearing Up.

Foreman	$3.40	13	$44.20	$0.09
11 laborers	1.17	143	107.31	.36
Total for taking down forms, etc.			$200.00	$0.45
Engineering and supervision				.43
Grand total, 460 cu. yds. concrete				$6.46

The cofferdam work was done in connection with the construction of the fourth pier, this pier being the only one coming in the bed of the river to be built entirely new. The work on this was started in water about 6 ft. deep. The 37 cu. yds. of concrete are included in the total of 460 cu. yds. in the above tabulation. By itself the cost of the cofferdam work, not including cost of cement, sand and slag, was as follows:

	Total.	Per cu. yd. Concrete.
Lumber	$ 45.00	$1.21
Labor, excavating	113.32	3.06
Labor, concrete	134.88	3.64
Total 37 cu. yds. concrete		$7.91

Cost of a Cofferdam and Concrete Pier on Pile Foundation.—The following was published in *Engineering-Contracting*, May 29, 1907:

This pier (Fig. 14) was built in water averaging 5 ft. deep. The cofferdam consisted of triple-lap sheet piling, of the Wakefield pattern, the planks being 2 ins. thick, and spiked together so as to give a cofferdam wall 6 ins. thick. The cofferdam enclosed an area 14x20 ft., giving a clearance of 1 ft. all around the base of the concrete pier, and a clearance of 2 ft. between the cofferdam and the outer edge of the nearest pile. The cofferdam sheet piles were 18 ft. long, driven 11 ft. deep into sand, and projecting 2 ft. above the surface of the water.

The concrete base resting on the foundation piles was 12x18 ft. The concrete pier resting on this base was 7x13 ft. at the bottom,

and 5x11 ft. at the top. The pier supported deck plate girders. There were 100 cu. yds. of concrete in the pier and base.

The cost of this pier, which is typical of several others built at the same time, was as follows:

Setting Up and Taking Down Derrick and Platform—

4 days foreman at $5.00	$20.00
¾ days engineman at $3.00	2.25
¾ days blacksmith at $3.00	2.25
¾ days blacksmith helper at $2.00	1.50
22 days laborers at $2.00	44.00
Total	$70.00

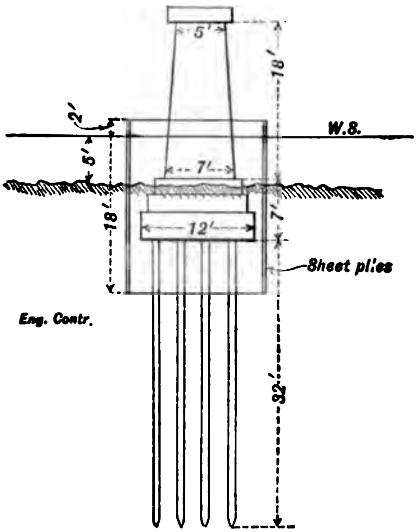


Fig. 14.—Bridge Pier on Piles.

Cofferdam—

7 days foreman at $5.00	$35.00
4 days engineman at $3.00	12.00
38 days laborers at $2.00	76.00
1 ton coal at $3.00	3.00
Total labor on 7,900 ft. B. M. at $16.00.	$126.00
7,900 ft. B. M. at $20.00	158.00
Total for 58 cu. yds. excav. at $5..	$284.00

Wet Excavation—

1.8 days foreman at $5.00	$9.00
1.5 days engineman at $3.00	4.50
9 days laborers at $2.00	18.00
½ ton coal at $3.00	1.50
Total labor on 58 cu. yds. at 57c	$33.00

Foundation Piles—

960 lin. ft. at 10c	$96.00
4 days setting up driver and driving 24 piles at $20 per day for labor and fuel	80.00
Total	$176.00

Concrete—

100 cu. yds. stone at $1.00	$100.00
40 cu. yds. sand at $0.50	20.00
100 bbls. cement at $2.00	200.00
5 days foreman at $5.00	25.00
50 days laborers at $2.00	100.00
5 days engineman at $3.00	15.00
2 tons coal at $3.00	6.00
Total, 100 cu. yds. at $4.66	$466.00
8 days carpenters at $3.00	$ 24.00
2,400 ft. B. M. 2-in. plank at $25.00	60.00
1,000 ft. B. M. 4x6-in. studs at $20.00	20.00
Nails, wire, etc	2.00
Total forms for 100 cu. yds. at $1.06	$106.00

Summary—

Setting up derrick, etc	$ 70.00
Cofferdam (7,000 ft. B. M.)	284.00
Wet excavation (58 cu. yds.)	33.00
Foundation piles (24)	176.00
Concrete (100 cu. yds.)	466.00
Forms (3,400 ft. B. M.)	106.00
Total	$1,135.00
Transporting plant	20.00
20 days rental of plant at $5.00	100.00
Total cost of pier	$1,252.00

Regarding the item of plant rental, it should be said that the plant consisted of a pile driver, a derrick, a hoisting engine, and sundry timbers for platforms. There was no concrete mixer. Hence an allowance of $5 per day for use of plant is sufficient.

It will be noted that no salvage has been allowed on the lumber for forms. As a matter of fact, all this lumber was recovered, and was used again in similar work.

Referring to the cost of cofferdam work, we see that, in order to excavate the 58 cu. yds. inside the cofferdam, it was necessary to spend $284, or nearly $5 per cu. yd., before the actual excavation was begun. The work of excavating cost only 57 cts. per cu. yd., but this does not include the cost of erecting the derrick which was used in raising the loaded buckets of earth, as well as in subsequently placing the concrete. The sheet piles were not pulled, in this instance, but a contractor who understands the art of pile pulling would certainly not leave the piles in the ground. A hand pump served to keep the cofferdam dry enough for excavating; but in more open material a power pump is usually required.

The above costs are the actual costs, and do not include the contractor's profits. His bid on the work was as follows:

Piles delivered	12 ct. per ft.
Piles driven	$5 each
Cofferdam	$37 per M.
Wet excavation	$1.00 per cu. yd.
Concrete	$8.00 per cu. yd.

In order to ascertain whether or not these prices yielded a fair profit, it is necessary to distribute the cost of the plant transportation and rental over the various items. We have allowed $120 for plant transportation and rental, and $70 for setting up and taking down the plant, or $190 in all. The working time of the plant was as follows:

	Days.	Per cent of time.	Prorated plant cost.
Cofferdam	7	39	$ 74
Excavation	2	11	21
Foundation piles	4	22	42
Concrete	5	28	53
Total	18	100	$190

As above given, the labor on the 7,900 ft. B. M. in the cofferdam cost $126, or $16 per M.; but this additional $74 of prorated plant costs, adds another $9 per M., bringing the total labor and plant to $25 per M., to which must be added the $20 per M. paid for the timber in the cofferdam, making a grand total of $45 per M. This shows that the contractor's bid of $37 per M. was much too low.

The labor on the excavation cost 57 cts. per cu. yd., to which must be added the prorated plant cost of $21 distributed over the 58 cu. yds., or 36 cts. per cu. yd., making a total of 93 cts. per cu. yd. This shows that the bid of $1 per cu. yd. was hardly high enough.

The labor on the 24 foundation piles cost $80, or $3.33 each. The prorated plant cost is $42, or $1.75 per pile, which, added to $3.33, makes a total of $5.08. This shows that the bid of $5 per pile for driving was too low. However, there was a profit of 2 cts. per ft., or 80 cts. per pile, on the cost of piles delivered.

The concrete amounted to 100 cu. yds. Hence the prorated plant cost of $53 is equivalent to 53 cts. per cu. yd. Hence the total cost of the concrete was:

	Per cu. yd.
Cement, sand and stone	$3.20
Foreman (at $5)	0.25
Labor (at $2)	1.00
Engineman (at $3)	0.15
Coal (at $3)	0.06
Carpenters (at $3)	0.24
Forms (at $23.50, used once)	0.80
Wire nails, etc.	0.02
Prorated plant cost	0.53
Total	$6.25

Since the contract price for concrete was \$8 per cu. yd., there was a good profit in this item.

It is doubtful whether many contractors analyze their costs in this manner, prorating plant costs and like, but no other method is satisfactory. Such an analysis frequently discloses the economy of radically changing the method of doing the work. For example, on abutment work, and on some piers, it is often wise not to erect a derrick at all, but to build inclined runways up which to wheel the concrete. As the pier or abutment rises in height, the runways are raised. The added cost of labor is more than offset by the saving in the cost of transporting and erecting a derrick where the yardage to be moved is small.

In like manner the excavation of a small amount of earth from the cofferdam may be more economically accomplished by shoveling it out in "lifts," than by installing a derrick for the purpose.

On the other hand, few contractors have given much study to economic methods of erecting and moving derricks, etc. A little brains put into this end of the work, may abundantly justify the use of derricks even on small jobs.

We urgently recommend the careful recording and analysis of the cost of erecting and shifting plants, as well as a similar analysis of all other costs.

The foregoing analysis should make it clear to engineers that seemingly high bids on work involving one or more small units of construction, may, in fact, prove to be too low.

Cost of a Pneumatic Caisson and Masonry Bridge Pier.*—The following data relate to the cost of labor and materials required for three railway bridge piers built by the pneumatic caisson process. The work was done for the railway company in the state of Washington, by a contractor working on a percentage basis, but the costs are the actual costs, not including the contractor's percentage.

Borings were made along the line of the bridge and the bottom was penetrated with a 2-in. pipe to a depth of 34 ft. below extreme low water. The material encountered was a very uniform bed of fine sand.

Plant.—A scow 30 ft. x 80 ft. x 4 ft. was built and was equipped with 3 boilers having an aggregate capacity of 125 hp. There were 2 air compressors; 1 air receiver; 1 duplex Knowles pump, with 12x18-in. cylinders and 60-in. discharge; 1 small pump for supplying water into the receiver; 3 air locks, 4 ft. diameter by 8 ft. high; 8 sections main air shaft, 3 ft. diameter by 8 ft. high; 2 hoppers, 3 ft. diameter by 2¾ ft. high, for 18-in. supply shaft; rubber hose, various iron pipes, etc.

Pneumatic Caissons, Pier No. 2.—There were three caissons. Pier No. 2 was a pivot pier, supporting a single track draw bridge 240 ft. long. Piers Nos. 1 and 3 supported the ends of this draw span and the two 70-ft. plate girder spans approaching it.

**Engineering-Contracting*, May 8, 1907.

The caisson for this pivot pier was 30x30 ft. square and 15 ft. high. It was built of 12x12-in. surfaced timbers, sheeted both outside and inside with 3-in. surfaced plank, nailed vertically, and calked with oakum. The cutting edge was made of ⅜-in. iron, 3 ft. high, with shoulder 2 ft. wide, stiffened by brackets at intervals of 1 ft. to 2½ ft. The 12x12 timbers were drift bolted together with 1-in. bolts, and the whole structure tied with 1½-in. and 2-in. rods. The corners were protected by ¼-in. iron plates.

The cutting edge of the caisson was sunk to a depth of 55 ft. below water level or 45 ft. below ground level, requiring the excavation of 1,500 cu. yds.

When the caisson was built up 10 ft. above the cutting edge, the inside and the outside linings were spiked on and calked. The bottom sections of the supply shaft and air lock were inserted and tightly fitted. A temporarily false bottom of 3-in. plank, well calked, was made for the purpose of floating the caisson into place, after which the work of adding to its height was continued.

Meanwhile 11 guide piles were driven to guide the caisson during sinking.

The day after the caisson was in position the filling of the top part with concrete was begun, and lasted five days. Compressed air was introduced into the caisson the second day after it was in position, and on the third day three eight-hour shifts began work, the first work being the chopping out of the false bottom referred to above. By this time a cofferdam, 16 ft. high, had been constructed on top of the caisson, so as to prevent floods from interfering with the work.

It required just 29 days of 24 hrs. to sink the caisson 45 ft. after it was in place, although the actual time of sinking was 19 days, there being several delays. Then the working chamber was filled with concrete. Sections 2 ft. by 2 ft. were dug out under the shoulder of the cutting edge, and successively filled with concrete. Having thus supported the caisson, the center portion was excavated and filled with concrete. The filling of the working chamber and lower air locks with concrete took 7 days. The compressed air was then taken off, having been used for 36 days. The depth sunk was 45 ft., or 1¼ ft. per day.

The masonry on top of the caisson was finished 18 days after the compressed air had been turned off, so that 54 days after the caisson had been floated to place the pier was ready to receive the bridge.

The masonry on top of the caisson consisted of an annular cylinder of cut stone masonry, 50 ft. high, having a thickness of 4½ ft. at the base and 3½ ft. at the top. This cylinder was filled with concrete. The outside diameter of the masonry cylinder was 25 ft. at the top and 29 ft. at the base. The height of this masonry cylinder was 50 ft. The cost of the plant was as follows:

The scow was 30x80x4 ft., provided with a boiler house, and its cost was:

30,600 ft., B. M., timber in scow at $15	$459.00
1,400 lbs. boat spikes at 4c	56.00
800 lbs. bolts, screws, etc., at 3c	24.00
2,000 lbs. oakum at 4c	80.00
5 bbls. tar at $5	25.00
Miscellaneous materials	20.00
Total materials in scow	$664.00
22,000 ft., B. M., in boiler house at $15	$330.00
1,200 lbs. nails, etc	40.00
800 lbs. tarred paper at 2½c	20.00
1,000 brick	8.00
1 bbl. lime	1.50
Miscellaneous materials	10.00
Total materials in boiler house	$409.50

Labor building scow and boiler house:

15 days, foreman, at $4	$ 60.00
240 days, carpenters, at $3.05	720.00
50 days, laborers, at $2	100.00
Total labor	$880.00

This labor cost is equivalent to $16 per 1,000 ft., B. M., of timber in the scow and boiler house. The cost of setting up the boilers, compressors, etc., was as follows:

12 days, foreman, at $4	$ 48.00
24 days, carpenter, at $3	72.00
4 days, machinist, at $5	20.00
3 days, blacksmith, at $3.50	10.50
50 days, steam fitter, at $3.50	175.00
24 days, engineman, at $3.50	84.00
270 days, laborer, at $2	540.00
387 days. Total	$949.50

This cost is also excessive and indicates very poor management. The freight on this plant was $150. Summarizing, we have:

Scow and boiler house	$1,950
Setting up boilers, etc.	950
Freight	150
Total	$3,050

Charging this $3,050 to the three piers according to their size, we may assign 50 per cent, or $1,525, to Pier No. 2, and $762 to each of the other two piers.

The three boilers, two air compressors, pumps, etc., were worth about $4,000, and a very liberal allowance for their use on this job would be $2,000, charging 50 per cent, or $1,000, to Pier No. 2, and $500 to each of the other two piers. This $1,000 added to the $1,525, makes $2,525 charged for plant. The cost of erecting a platform and derrick at Pier No. 2 was $100. About 250 ft. of 4-in. pipe and 70 ft. of 1½-in. pipe and fittings, costing $130, were left in the caisson and not recovered.

About 36,000 lbs. of iron were required for the air locks, shafts, etc., of the three piers. About half of it, or 18,000 lbs., was left

in the piers, for which a charge of 5c per lb. was made, or $900, or $300 per pier.

The cost of materials in the caisson (30x30x15 ft.) was as follows:

71,000 ft. B. M. in caisson at $20	$1,420.00
4,400 ft. B. M. in false floor at $20	88.00
3,400 ft. B. M. in inside curbing at $20	68.00
9,000 ft. B. M. in cofferdam	180.00
15,000 lbs. cutting edge at 4½c	675.00
1,400 lbs. corner plates at 4c	56.00
5,200 lbs. rods at 2½c	130.00
4,000 lbs. drift bolts at 2½c	100.00
3,000 lbs. boat spikes at 2c	60.00
800 lbs. cast washers at 2c	16.00
1,000 lbs. lag screws, etc., at 4c	40.00
20 bales (2,000 lbs.) of oakum at $4	80.00
100 lbs. rubber packing at 70c	70.00
Total materials	$2,983.00

There were 78,800 ft. B. M. in the caisson, exclusive of the 9,000 ft. B. M. in the cofferdam. The cost of framing and erecting the caisson was as follows:

45 days, foreman, at $4	$ 180.00
320 days, carpenters, at $3	960.00
90 days, laborers, at $2	180.00
14 days, blacksmiths, at $3.50	49.00
10 days, engineman, at $3.50	35.00
7 days, machinist, at $5	35.00
486 days, total, at $2.96	$1,439.00

This is equivalent to $18.25 per 1,000 ft. B. M., which is a very high cost for this kind of work.

The cost of building the cofferdam on top of the caisson was as follows:

6 days, foreman, at	$4.00	$ 24.00
60 days, carpenters, at	3.00	180.00
10 days, laborers, at	2.00	20.00
3 days, blacksmith, at	3.50	10.50
79 days, total	$2.97	$234.50

Since there were 9,000 ft. B. M. in the cofferdam, the labor cost $26 per 1,000 ft. B. M.

The cost of sinking the caisson, which included tamping the concrete in the working chamber of the caisson also, was as follows:

34 days, foreman machinist, at	$5.00	$ 170.00
16 days, general foreman, at	6.00	96.00
80 days, sub foreman, at	5.00	400.00
64 days, top lock tender, at	2.25	144.00
720 days, pressure men, at	3.50	2,520.00
72 days, enginemen, at	3.50	252.20
72 days, firemen, at	2.75	198.00
32 days, coal passers, at	2.50	80.00
40 days, wipers, at	2.00	80.00
50 days, steam fitters, at	3.00	150.00
4 days, blacksmith, at	3.50	14.00
58 days, carpenters, at	3.00	174.00
360 days, laborers, at	2.00	720.00
32 days, signal man, at	2.00	64.00
32 days, call boy, at	1.00	32.00
1,706 days total	$2.99	$5,094.20

As above stated, it required 36 days to sink the caisson and fill the working chamber with concrete, hence by dividing each of the above items by 36 we get the number of each kind of men per day.

In addition to the materials and labor above enumerated, there were the supplies, which cost as follows:

220 tons coal at $3	$660.00
220 gals. gasoline and kerosene, at 10c	20.00
40 gals. valve oil at 50c	20.00
20 gals. engine oil at 35c	7.00
70 lbs. waste at 5c	3.50
45 prs. rubber boots at $3	135.00
Total	$845.50

The guide piles around the caisson were driven with a scow driver, and cost as follows:

600 lin. ft. piles at 10c	$ 60.00
Labor driving	52.00
Coal for driver, etc.	20.00
Total	$132.00

There were 400 cu. yds. of concrete placed in the working chamber of the caisson and 400 cu. yds. inside the stone masonry on top of the caisson. The cost of this concrete was as follows:

	Per cu. yd.
1 cu. yd. stone at $1	$1.00
0.45 cu. yd. sand at 80c	.36
0.7 bbl. cement at $2	1.40
Mixing and placing	1.15
Erecting derricks, platforms, etc.	.34
Total	$4.25

The $1.15 for "mixing and placing" covers the wages of the men ($2 a day) engaged in hand mixing and handling the concrete, the derrick engineman, the foreman, the lock tenders, and the coal; but it does not include the placing and tamping of the concrete in the working chamber of the caisson, for that item is included in the cost of sinking the caisson.

There were 400 cu. yds. of concrete in the caisson and 400 cu. yds. of concrete on the top of it, but of this last 400 cu. yds. only 60 per cent, or 240 cu. yds., was below the ground level. Hence we have $400 + 240 = 660$ cu. yds. of concrete below the ground level. This 660 cu. yds., at $4.25, cost $2,805, which is equivalent to $62 per lin. ft., or $1.93 per cu. yd. of pier below the ground level.

We may now summarize the cost as follows:

	Total.	Per lin. ft. (45 ft.)	Per cu. yd. (1,500 cu. yds.)
Plant, proportionate cost	$2,525	$ 56	$1.68
Setting up platform and derrick	100	2	0.07
Pipe left in caisson	130	3	0.09
6,000 lbs. iron left in caisson	300	7	0.20
78,800 ft. B. M. caisson, $20	1,576	35	1.05
9,000 ft. B. M. cofferdam, $20	180	4	0.12
15,000 lbs. cutting edge, 4½c	675	15	0.45
9,200 lbs. rods, drifts, etc., 2½c	230	5	0.16
6,200 lbs. boat spikes, etc.	172	4	0.11
2,200 lbs. oakum, 4c	80	2	0.05
100 lbs. rubber packing, 70c	70	2	0.05
486 days bldg. caisson, $2.96	1,439	32	0.96
79 days building cofferdam, $2.97	235	5	0.16
1,076 days sinking, $2.99	5,094	112	3.39
220 tons coal, $3.00	660	15	0.44
Other supplies	185	4	0.12
600 lin. ft. piles delivered, 10c	60	1	0.04
600 lin. ft. piles driven, 12c	72	2	0.05
Supt. and office exp	700	16	0.47
Totals	$14,483	$322	$9.66

The cost of cutting and handling the sandstone for the masonry was as follows:

	Per cu. yd.
2.8 days, stone cutter, at $6	$1.68
3.2 days, laborer, at $2	0.64
0.04 day, blacksmith, at $3.50	0.14
0.04 day, blacksmith helper, at $2.50	0.10
0.06 day, horse, at $1.50	0.09
Total	$2.65

The total cost of this stone masonry was as follows:

	Per cu. yd.
1 cu. yd. stone at $6.50	$ 6.50
Cutting stone	2.65
Setting stone	0.95
0.08 cu. yd. sand at 80c	0.05
0.2 bbl. cement at $2	0.40
Total	$10.55

There were 600 cu. yds. of this stone masonry, hence its cost was $6,330. About 60 per cent of it, or $3,798, was below the ground level.

Summarizing the cost of the pier below the ground level, we have:

	Total.	Per lin. ft.	Per cu. yd.
Brought forward	$14,483	$322	$ 9.66
Concrete at $4.25	2,805	62	1.93
Masonry at $10.55	3,798	84	2.53
Total	$21,086	$468	$14.12

The cost of the 20 lin ft. of pier above the ground level was:

160 cu. yds. concrete at $4.25	$ 680
240 cu. yds. masonry at $10.55	2,532
Total, 20 lin. ft., at $160	$3,212

The total cost of the pier was $24,298.

The reader will note that the tabulated cost of this caisson is given in such shape that the cost of similar work can be easily estimated by allowing for differences in prevailing prices and wages. If timber costs $30 per M, instead of $20, then, by adding 50 per cent to the items involving timber, the increased cost per cubic yard of caisson is readily estimated. Since the timber in the caisson cost $1.05 per cu. yd. of caisson, when timber was $20 per M, it is evident that, with timber at $30 per M, this item of $1.05 will be increased 50 per cent, making it $1.58 per cu. yd. of caisson. In like manner other items may be raised or lowered, almost by inspection, and a total secured which will be a very accurate estimate. The above costs do not include "engineering," which, in this case, was about 6 per cent of the total.

In a succeeding issue will be given the cost of the two caissons (piers Nos. 1 and 3) mentioned in the first part of this article; and in that issue we shall compare the costs of caissons in piers Nos. 1, 2 and 3, showing that the cubic yard is the proper unit to use in recording and comparing the cost of caisson work, and not the lineal foot. The lineal foot, it is true, has long been regarded as a convenient unit of caisson costs, but it is wholly unreliable for comparative purposes, and should be abandoned.

Cost of Two Pneumatic Caissons and Masonry Bridge Piers.*—In our last issue we gave a general description of a large pivot pier caisson and plant used in sinking it to a depth of 45 ft. In this issue we shall give the itemized cost of two smaller caissons of the same type, sunk with the same plant described in our last issue, and under the same conditions. Each of these caissons was 16 x 34 ft. in cross-section, and 15 ft. high; and on top of each was built the masonry pier as fast as the caisson was sunk. These two "rest piers" will be designated as piers No. 1 and No. 3. The masonry was built to a height of 51 ft. above the top of the caisson, or 13 ft. above water level. The cutting edge of the caisson of pier No. 1 reached 47 ft. below ground level, or 53 ft. below water level. The cutting edge of pier No. 3 reached the same distance below water level, but only 38 ft. below ground level.

The masonry of each pier had a cross-section of 11 x 28 ft. at the base, and 7 x 24 ft. under the coping. The masonry was cut stone (sandstone), excepting a core or concrete, 4 x 19 ft., 29 ft. high above the top of the caisson. The working chamber of the caisson was filled with concrete after it had been sunk to the proper depth.

Cost of Pier No. 1.—Eighteen days after the caisson was launched the sinking was begun. Eleven days after the sinking began, the sinking was completed, but the compressed air was not taken off until 17 days after the sinking began. The masonry pier was completed 54 days after the sinking began.

Since the cross-section of the caisson was 544 sq. ft. and it was sunk to a depth of 47 ft., the excavation amounted to 947 cu. yds.

The proportionate charge for the use of the plant for this pier was $1,262.

Engineering-Contracting, May 15, 1907.

There were 6,000 lbs. of iron (air shafts, etc.) left in the pier, for which a charge of 5 cts. per lb., or $300, was made.

There were 160 ft. of 4-in. pipe, and 40 ft. of 1½-in pipe and fittings, worth $100, left in the pier.

The cost of materials in the caisson was as follows:

	Total.	Per Lin. Ft. (47 ft.)	Per Cu. Yd. (947 cu. yds.)
Plant, proportionate cost	$1,262	$ 27	$ 1.33
Setting up derrick and platform	90	2	0.10
Pipe left in caisson	100	2	0.10
6,000 lbs. iron left in caisson	300	6	0.32
51,000 ft. B. M. caisson, $20	1,020	22	1.08
13,000 lbs. cutting edge, 4½ cts.	585	13	0.62
8,000 lbs. rods and drifts, 2½	200	4	0.21
5,000 lbs. boat spikes, etc.	136	3	0.14
1,500 lbs. oakum, 4 cts.	60	1	0.06
100 lbs. rubber packing, 70 cts.	70	2	0.07
321 days building caisson, $2.94	945	21	1.00
943 days sinking caisson, $3.10	2,929	62	3.09
100 tons coal, $3.00	300	6	0.32
Other supplies	109	2	0.11
Supt. and office expense	440	9	0.47
Total	$8,546	$182	$ 9.02
280 cu. yds. concrete, $4.25	1,190	25	1.25
Total	$9,736	$207	$10.27

46,000 ft. B. M. in caisson, at $20	$ 920
2,000 ft. B. M. in false floor, at $20	40
13,000 lbs. cutting edge, at 4½ cts.	585
1,300 lbs. corner plates, at 4 cts.	52
5,000 lbs. rods, at 2½ cts.	125
3,000 lbs. drift bolts, at 2½ cts.	75
2,400 lbs. boat spikes, at 2 cts.	48
800 lbs. cast washers, at 2 cts.	16
500 lbs. lag screws, etc., at 4 cts.	20
15 bales (1,500 lbs.) oakum, at $4	60
100 lbs. rubber packing, at 70 cts.	70
Total materials	$2,071

There were 51,000 ft. B. M. in the caisson.

The cost of framing and erecting the caisson was:

30 days, foreman, at	$4.00	$120.00
220 days, carpenters, at	3.00	660.00
60 days, laborers, at	2.00	120.00
7 days, blacksmith, at	3.50	24.50
4 days, machinists, at	5.00	20.00
321 days, total, at	$2.94	$944.50

This is equivalent to $18.50 per 1,000 ft. B. M., which is a very high cost.

The cost of sinking the caisson, which includes tamping the concrete in the caisson also, was as follows:

18 days, foreman machinist, at	$5.00	$ 90
24 days, general foreman, at	6.00	144
48 days, sub-foremen, at	5.00	240
36 days, top lock tender, at	2.25	81
380 days, pressure men, at	3.50	1,330
44 days, enginemen, at	3.50	154
44 days, firemen, at	2.75	121
38 days, coal passers, at	2.50	95
24 days, steamfitters, at	3.00	72
2 days, blacksmith, at	3.50	7
30 days, carpenter, at	3.00	90
250 days, laborers, at	2.00	500
5 days, call boy, at	1.00	5
943 days, total, at	$3.10	$2,929

The coal supplies used in sinking the caisson were as follows:

100 tons coal, at $3	$300.00
70 gals. gasoline and kerosene, at 10 cts.	7.00
160 lbs. candles, at 12 cts.	19.20
3,000 ft. B. M. in inside curb, at $20	60.00
20 lbs. valve oil, at 50 cts.	10.00
10 lbs. engine oil, at 35 cts.	3.50
35 lbs. waste, at 5 cts.	1.75
20 pairs rubber boots, at $3	60.00
100 lbs. red lead, at 8 cts.	8.00
Total	$409.45

There were 200 cu. yds. of concrete placed in the working chamber of the caisson and 80 cu. yds. in the pier, the cost being $4.25 per cu. yd., as given in our last issue.

We may now summarize the total cost as follows:

In addition to the above there were 480 cu. yds. of stone masonry, the actual cost of which was $10.55 per cu. yd., or $5,064. About 330 cu. yds. of this masonry was below the ground level, which is equivalent to $3,481 of stone masonry below the ground level. Dividing this by 47, we have $74 per lin. ft.

Summarizing, we have the following cost of pier No. 1 below the ground level:

	Total.	Per lin. ft.	Per cu. yd.
Caisson, etc.	$ 8,546	$182	$ 9.02
280 cu. yds. concrete at $4.25	1,190	25	1.25
330 cu. yds. masonry, at $10.55	3,481	74	3.66
Total	$13,217	$281	$13.93
150 cu. yds. masonry above ground level, at $10.55	1,583		
Grand total	$14,800		

Cost of Pier No. 3.—The design of this pier was the same as of Pier No. 1. It differed somewhat in cost, however, since it was sunk to a depth of only 38 ft. below ground level, due to the fact that the water was deeper at the site of this pier than at the site of pier No. 1.

Fifteen days after the caisson was launched, the sinking began. It took 15 days to sink the caisson, and 4 days more to fill the

working chamber with concrete, making 19 days of work under air pressure. The masonry pier was completed 37 days after the sinking was begun. The cost of materials in the caisson was the same as for pier No. 1.

The cost of framing and erecting the caisson was:

29 days,	foreman	$4.00	$116.00
218 days,	carpenters	3.00	654.00
58 days,	laborers	2.00	116.00
9 days,	blacksmith	3.50	31.50
4 days,	machinist	5.00	20.00
318 days,	total	$2.95	$937.50

This is equivalent to $19 per M.

The cost of sinking the caisson, which included tamping the concrete in the caisson also, was as follows:

18 days,	foreman machinist	$5.00	$ 90.00
30 days,	general foreman	6.00	180.00
38 days,	sub-foreman	5.00	190.00
33 days,	top lock tender	2.00	66.00
340 days,	pressure men	3.50	1,190.00
50 days,	enginemen	3.50	175.00
46 days,	firemen	2.75	126.50
20 days,	coal passers	2.50	50.00
28 days,	steamfitters	3.00	84.00
2 days,	blacksmith	3.50	7.00
16 days,	carpenter	3.00	48.00
220 days,	laborers	2.00	440.00
851 days,	total	$3.11	$2,646.50

The coal and supplies used in sinking the caisson were as follows:

120 tons coal, $3	$360.00
70 gals. gasoline, etc., 10 cts.	7.00
175 lbs. candles, 12 cts.	21.00
20 gals. valve oil, 50 cts.	10.00
12 gals. engine oil, 35 cts.	4.20
35 lbs. waste, 5 cts.	1.75
24 pairs rubber boots, $3	72.00
100 lbs. red lead, 8 cts.	8.00
Total	$483.95

The guide piles cost as follows:

620 lin. ft., delivered, 10 cts.	$ 62.00
620 lin. ft. driven, 10 cts.	62.00
Total	$124.00

Summarizing we have:

	Total.	Per Lin. Ft. (38 ft.)	Per Cu. Yd. (766 cu. yds.)
Plant	$1,262	$ 33	$ 1.65
Setting up derrick and platform	120	3	0.16
Pipe left in caisson	150	4	0.20
6,000 lbs. iron left in caisson	300	8	0.39
50,000 ft. B. M. left in caisson, $30	1,000	26	1.31
13,000 lbs. cutting edge, 4½ cts.	585	15	0.76
8,000 lbs. rods and drifts, 2½ cts.	200	5	0.26
5,000 lbs. boat spikes, etc.	136	4	0.18
1,500 lbs. oakum, 4 cts.	60	2	0.08
100 lbs. rubber packing, 70 cts.	70	2	0.09
318 days building caisson, $295	938	25	1.22
851 days sinking caisson, $3.11	2,646	71	3.45
120 tons coal, $3.00	360	9	0.47
Other supplies	124	3	0.16
Supt. and office exp.	440	11	0.57
Total	$8,391	$221	$10.95
280 cu. yds. concrete, $4.25	1,190	31	1.55
Total	$9,581	$252	$12.50

In addition to the above there were 480 cu. yds. of stone masonry, the cost of which was $10.55 per cu. yd., or $5,064. Adding this to the $9,581, we have a total cost of $14,645 for pier No. 3.

Let us compare the costs of piers Nos. 1, 2 and 3. Referring to our issue of May 8, we find the cost of pivot pier No. 2. In making the comparison we shall exclude the cost of the masonry and concrete.

	No. 1.	No. 2.	No. 3.
Cost per cu. yd., displaced	$9.02	$9.66	$10.95
Cost per lin. ft. below ground level	1.82	3.22	2.21

It is perfectly evident, from this comparison, that the lineal foot of distance sunk below the ground level is not a rational unit to be used in comparing the cost of pneumatic caisson work. On the other hand, the cubic yard of displaced earth is a much more rational unit. Obviously the cost of the masonry should be estimated separately, excepting possibly the concrete used in filling the working chamber of the caisson.

The foregoing data relate to work carried on at moderate depths below the water level.

Cost of a Caisson in Arizona.—Mr. S. M. Rowe gives the following data relative to a caisson for the Red Rock cantilever bridge, built in 1889, across the Colorado River in Arizona for the Atlantic and Pacific R. R. Co.

The caisson was 30 x 60 ft. in cross-section and 17 ft. high, surmounted by a timber crib 47 ft. high, the height from the cutting edge to the top of the crib being 64 ft. The ordinary low water level was at the top of the crib, and the depth of water (at low water) was only 4 ft. The material penetrated was mostly sand, gravel and boulders. So compact was the material at a depth of 61 ft. that it was practically impossible to reach bed rock.

The caisson and crib were of Oregon pine, and the following was the bill of material:

	Ft. B. M.
Working chamber (incl. 3 ins. casing inside)	82,560
Roof, 8 ft. thick	155,904
Crib (incl. 3 ins. casing outside)	240,855
Total timber (neat)	479,319

Iron bolts and spikes	58,000 lbs.
Concrete in crib (47.7 cu. yds. per lin. ft.)	2,290 cu. yds.
Concrete in working chamber	580 cu. yds.
Total concrete	2,870 cu. yds.

It is stated that the timber weighed 35 lbs. per cu. ft. when well dried, and that it absorbed 28 lbs. of water per cu. ft.

There were 1,480 cu. yds. of solid timber and 2,870 cu. yds. of concrete, making a total of 4,350 cu. yds. as the volume of the caisson and crib, the timber being 34% of the total volume.

The total cost was $128,263, or nearly $30 per cu. yd., of which $16.50 is labor, which is an exceedingly high cost. The following is the itemized cost of the caisson:

Timber (480 M)	$ 7,665.02
Iron and steel (58,000 lbs.)	2,180.13
Piling	315.24
Tools and materials	8,415.65
Fuel and water	7,158.30
Cement for 2,870 cu. yds. concrete	9,568.00
Freight	13,363.20
Local and train service	2,790.96
Labor	71,754.02
Engineering	5,052.67
Total	$128,263.19

This did not include the building of a trestle across the river to the site of the caisson, which cost $6,288, nor the tracks to the quarry, which cost $7,313.

The following gives the labor cost for the different periods:

	Pay Roll.	Depth Sunk.	Labor Cost Per Lin. Ft.
November, 10 days	$ 2,612	9.9 ft.	$263
December, 31 days	10,027	23.4 ft.	429
January, 31 days	10,710	26.8 ft.	400

The last foot or two sunk in January cost $2,500 per ft. for labor.

In February, 11 days were spent, at a cost of $3,760 for total labor, filling the working chamber with 580 cu. yds. of concrete.

The air plant consisted of 3 compressors (two of which were double cylinders 16 x 24 ins., and one 12 x 18 ins. Two were used while excavating and one held in reserve. These were driven by two 75-hp. boilers and by one of 50 hp. The air plant was on a boat 24 x 60 ft. built for the purpose.

The stone for the concrete was a broken volcanic rock, with which the "mesas" were strewn, which was raked into windrows and hauled by wagons to a pile where it was loaded into a car.

Cost of a Caisson in Tennessee.—Mr. Hunter McDonald gives the following data relative to a caisson for a pivot pier of a railway swing bridge built in 1893 across the Tennessee River for the Nashville, Chattanooga & St. Louis Ry., by contract.

The caisson was 36 ft. square and 16 ft. high, surmounted by a crib 28 ft. high, making a total height of 44 ft. The cutting edge was sunk through gravel and sand to a depth of 44 ft. below low water. The caisson and crib were filled with 1 : 2 : 5 natural cement concrete. The contract price of the pivot pier was as follows:

119,792 ft. B. M. timber in caisson, at $38	$ 4,552.11
95,727 ft. B. M. timber in crib, at $28	2,680.37
54,975 lbs. iron, at 4 cts	2,199.00
96 lin. ft. shafting left in place, at $7	672.00
44 lin. ft. sinking below water level, at $344.81	15,172.42
313.4 cu yds. material removed through lock at $35	10,969.00
1,085.9 cu. yds. concrete in crib and pockets, at $6	6,515.40
233.5 cu. yds. concrete in air chamber, at $12	2,802.00
Total cost of caisson	$45,562.C0

Since the displacement of this 44 ft. caisson was 2,112 cu. yds., the cost was $21.57 per cu. yd., or $1,035 per lin. ft. of vertical height.

The cost of the stone masonry was:

415.62 cu. yds. face stone, at $12	$ 4,987.44
725.19 cu. yds. backing, at $7	5,076.33
24.52 cu. yds. coping, at $16	392.32
Total masonry	$10,456.09

The masonry was 48 ft. high above the top of the crib.

A caisson for a rest pier was 16¾ x 40½ ft. in cross-section, and displaced 1,107 cu. yds., and cost $19 per cu. yd., or $476 per lin. ft. of vertical height. It contained 115,000 ft. B. M. in caisson and crib and 672 cu. yds. of concrete.

Cost of Four Caissons.—Mr. B. L. Crosby gives the following data relative to 4 caissons built in 1892 for the St. Louis, Keokuk & Northwestern R. R. for a double-track bridge across the Missouri River. The work was done by company forces. Each caisson was 30 x 70 ft. in cross-section and 16 ft. high, surmounted by a crib. The cribs were 24, 45, 58 and 64 ft. high for piers Nos. 1, 2, 3 and 4, respectively. The caissons and cribs were filled with 1 : 2 : 4 natural cement concrete.

The air plant consisted of two No. 4 Clayton duplex compressors, having steam and air cylinders, each 14 ins. with 15-in. stroke; and a Worthington duplex pump, 18½ x 10¼ x 10 ins. This plant was set on a small steam boat. There was a duplicate plant mounted on a platform on piles. There were several hoisting engines, a pile-driver boat, provided with a derrick for handling the timbers, and an arc light plant for night work. The concrete was mixed

in a Cockburn Barrow Co. mixer on a barge provided with a derrick for handling concrete blocks. There were several other barges for handling timber, cement and stone, and a small steamboat for towing barges.

The caissons were built on launching ways constructed of piles capped with 12 x 12-in. timbers parallel with the river bank. The way timbers were 12 x 12-in. having a slope of 3 ins. to the foot toward the river, and were extended far enough into the river to allow the caisson to float before being clear of the timbers. The piles under water were cut off with a circular saw and caps were placed by a diver; the drift-bolts were driven by a ramrod working through a gas pipe over the drift-bolt.

Several sandbars at the sites of the piers were washed away by the paddle wheels of the steamboat, a hole 7 to 10 ft. deep being dug out in this manner. Barges were placed on each side of a caisson, and heavy timbers bolted the caisson, extending out over the barges. By pumping air into the caisson it was raised till it drew only 5 ft. of water, and blocking was placed under the timbers projecting over the barges. Then it was towed to place.

The following were the depths below "standard low water" to which the different caissons were sunk: No. 1, 68 ft.; No. 2, 89 ft.; No. 3, 101 ft.; No. 4, 83 ft.

Some blasting of the rock site of caisson No. 1 was done. Rackarock was used, because its fumes do not give the men headaches as do the fumes of dynamite in a caisson.

The total combined height of the four caissons and cribs was 255 ft., and, since their cross-section was 30 x 70 ft., this is equivalent to combined displacement of nearly 20,000 cu. yds., of which 25% was the yellow pine timber, there being 1,609,000 ft. B. M. There were 13,285 cu. yds. of 1 : 2 : 4 concrete placed in the caissons and cribs, requiring 20,800 bbls. of cement, of which 80% was natural and 20% Portland. The cost of the concrete was $5.36 per cu. yd., including all material and labor. The cost of framing the timber and building it into the caissons was $22 per 1,000 ft. B. M., including the cost of the launching ways, handling and towing, and all labor and materials, but not including the cost of the timber in the caissons and cribs. It is likely that in 1892 this yellow pine cost about $18 per M. In which case the total cost was $40 per M in place. Since 1,000 ft. B. M. = 3.08 cu. yd., each cubic yard of timber would cost $13. If each cubic yard displaced by the caisson and cribs was 25% timber (at $13 per cu. yd.) and 75% concrete (at $5.36 per cu. yd.), then the average cost was $7.20 per cu. yd., to which must be added the cost of sinking the caissons, which was $2.48 per cu. yd., making a total of $9.68 per cu. yd. displaced. As a matter of fact the total cost actually was $9.23 per cu. yd., from which it would appear either that our assumed price of $18 per M for the timber is a little too high, or that the percentage of timber was not quite 25%.

The material was excavated and discharged from the working chambers with a Morrison sand pump, which is a modification of the Eads sand pump.

For comparative purposes it is well to record here that a long timber trestle, built at the same time by company forces, cost $7.42 per M for labor, including unloading, framing and erecting.

Wages are not given, except for "pressure men," who received $3.50 a day, and worked an hour at a time for 2 or 3 hrs. a day when at the greatest depth. It is probable that common laborers received $1.25 to $1.50 and carpenters $2.50 per day of 10 hrs., at that time and place.

Materials for a Caisson.—In building a single-track bridge for the Illinois Central R. R. across the Ohio River near Cairo, 10 piers were sunk 75 ft. below low water. The frictional resistance was found to be 600 to 700 lbs. per sq. ft. of exposed surface. The largest caisson and crib is 30 ft. wide, 70 ft. long and 50 ft. high. The total height of the pier is 177 ft. (50 ft. of caisson and crib filled with concrete, and 127 ft. of masonry on top). It contains the following materials:

331,000 ft. B. M. lumber.
137,000 lbs. iron.
2,865 cu. yds. concrete in caisson and crib.
3,800 cu. yds. masonry.

The pier measures 14 x 43 ft. on top.

The weight of the 137,000 lbs. of iron was distributed as follows:

	Lbs.
Cutting edge	26,583
Corner plates	8,108
Air locks (1 pr. doors left in)	7,287
Sections of shaft	14,813
Rods	30,570
Washers	7,111
Drift bolts	21,606
Boat spikes	15,402
Lag screws	265
Bolts	331
Pipe (334 ft. of 4 in.)	3,495
Pipe (83 ft. of 5 in.)	1,234
Total	136,785

Cost of Erecting Three Steel Viaducts and a New Formula for Computing the Weight of Viaducts.*—In *Engineering-Contracting* of April 3, 10 and 17 and May 8, we gave the costs of erecting a number of steel bridges of different spans and types. In this issue we shall give the cost of erecting several steel viaducts, and shall briefly discuss methods of estimating the cost of steel viaducts.

The modern steel viaduct is a structure consisting of deck plate girder spans supported by steel bents resting on concrete pedestals. Each steel bent has two legs, having a batter of 2 ins. to the foot. Bents on high viaducts are spaced 30 ft. and 60 ft. apart alternately, so that the plate girder spans are alternately 30 ft. and

*Engineering-Contracting, June 19, 1907.

60 ft. long. Every pair of bents 30 ft. apart is braced by horizontal and diagonal members, thus forming a "tower." Ordinarily, therefore, the number of towers in a viaduct is just half the number of bents; and the number of plate girder spans is just one more than the number of bents.

Estimating Weight of Viaducts.—There are excellent rules or formulas for estimating the approximate weight of plate girders and truss bridges of different spans, but the existing formulas for estimating the weight of viaducts are very unsatisfactory. The editors of this journal have deduced a new formula for estimating the weight of steel in viaducts of the type just described, but, before presenting the deduction, we shall quote the empirical formulas proposed by Mr. C. P. Howard, M. Am. Soc. C. E. They are as follows:

$W = 26\,A$, for height of 20 ft.

$W = 20\,A$, for height of 60 ft.

$W = 17\,A$, for height of 90 ft.

W = total weight of viaduct in lbs.

A = profile area of viaduct in square feet.

The above formulas are for Cooper's E 40 loading. Add 20% for Cooper's E 50 loading.

This method of estimating the weight of viaducts by profile areas alone is a very common one, but is wholly irrational, as is seen by the fact that a different factor is necessary for different heights. The profile area, it should be explained, is the area on the profile between the base of the rail and the ground surface, or between the lower chord of the plate girders and the line joining the tops of the masonry pedestals on which the towers rest. It is in the former sense (which is most common) that we use the term profile area here, although the latter sense is to be preferred and should be generally adopted. Obviously the weight of the bents, or towers, bears some relation to this area, but it is equally obvious that the weight of the plate girders bears no relation whatever to the profile area.

For a live load of two 116-ton engines and a train weighing 3,000 lbs. per sq. ft., the average weight of plate girder spans (30 ft. and 60 ft. alternating) is about 600 lbs. per lin. ft. For the same loading, the weight of steel in each bent is about 540 lbs. per lin. ft. of height of bent, for viaducts of any considerable height. Having these data in mind, we are able to deduce a very simple and rational formula for estimating the weight of steel in high viaducts.

Let A = profile area in sq. ft.

L = length of viaduct in ft.

W = weight of viaduct in lbs.

Then:

$$\text{Average height of bents} = \frac{A}{L}.$$

$$\text{Number of bents} = \frac{L}{45}.$$

This last equation is slightly in error, giving one bent too few when the average length of girders is 45 ft. (½ of 30 + 60), but it is close enough for practical purposes. Therefore:

$$\text{Total height of all bents} = \frac{A}{L} \times \frac{L}{45} = \frac{A}{45}.$$

But the weight of bents per lin. ft. of height is 540 lbs.; hence:

$$\text{Total weight of bents} = 540 \times \frac{A}{45} = 12\,A.$$

The total weight of girder spans = 600 L. Therefore:

$$W = 12\,A + 600\,L.$$

This is a formula which the editors have used in estimating the weight of many viaducts of different heights, and, except for very low viaducts (20 or 25 ft.), or for viaducts of antiquated design, it gives very close results. Low viaducts are really trestles, with bents spaced at equal distances, and not built with bents spaced and braced so as to form towers.

We shall now pass to a consideration of the cost of erecting two viaducts, and at the close of this article will discuss the design of masonry substructures, indicating wherein we believe present practice to be extravagantly wasteful of material.

Cost of Erecting a 500-ft. Viaduct.—This viaduct weighed 340 tons and was erected by contract. The profile area was 31,500 sq. ft., and the average height was 63 ft. The following costs were the actual costs to the contractor.

The average force was:

		Per day.
1	foreman at $5.00	$ 5.00
1	foreman carpenter, at $4.00	4.00
1	foreman, at $3.50	3.50
7	riveters, etc., at $3.25	22.75
10	bridgemen, at $3.00	30.00
8	carpenters, at $2.75	22.00
3	laborers, at $2.50	7.50
1	stationary engineer, at $3.25	3.25
1	water boy, at $1.50	1.50
33	Total gang	$99.50

It will be noted that foremen's wages constituted 12% of the total.

Time allowed traveling—

1 day at $5.00	$ 5.00
1 day at 4.00	4.00
1 day at 3.50	3.50
8 days at 3.25	26.00
10 days at 3.00	30.00
8 days at 2.75	22.00
3 days at 2.50	7.50
Total	98.00

Loading derricks and tools—

4 days at $5.00	$20.00
4 days at 3.50	14.00
12 days at 3.00	36.00
2 days at 2.50	5.00
Total	$75.00

Framing traveler and rig derrick car—

3 days at $5.00	$15.00
3 days at 3.50	10.50
6 days at 3.25	19.50
7 days at 3.00	21.00
Total	$66.00

Erecting traveler—

1½ days at $5.00	$ 7.50
9½ days at 3.25	30.87
9 days at 3.00	27.00
Total	$65.37

Erecting towers—

12 days at $5.00	$ 60.00
12 days at 3.50	42.00
36 days at 3.25	117.00
47 days at 3.00	141.00
12 days at 2.50	30.00
6 days at 1.50	9.00
Total	$399.00

Riveting towers—

48 days at $3.25	$156.00
52 days at 3.00	156.00
32 days at 2.50	80.00
7 days at 1.50	10.50
Total	$402.50

Filling bases of posts with concrete—

4 days at $2.75	$11.00

Erecting girder spans—

10 days at $5.00	$ 50.00
10 days at 3.50	35.00
40 days at 3.25	130.00
60 days at 3.00	180.00
5 days at 1.50	7.50
Total	$402.50

Riveting girder spans—

24 days at $3.25	$ 78.00
48 days at 3.00	144.00
12 days at 2.75	33.00
6 days at 1.50	9.00
Total	$264.00

Framing ties for floor—

10 days at $4.00	$ 40.00
33 days at 2.75	90.75
Total	$130.75

Laying floor—

16 days at $4.00	$ 64.00
16 days at 2.50	40.00
43 days at 2.75	118.25
Total	$222.25

Painting—first coat—

23½ days at $3.25	$ 76.37
26 days at 3.00	78.00
20 days at 2.50	50.00
Total	$204.37

Painting—second coat—

21 days at $3.25	$ 68.25
24 days at 3.00	72.00
16 days at 2.50	40.00
Total	$180.25

Summary—

Time traveling	$ 98.00
Loading derricks and tools	75.00
Framing traveler, etc.	66.00
Erecting traveler	65.37
Total general expense	$ 304.37
Erecting towers	399.00
Riveting towers	402.50
Filling bases of posts	11.00
Erecting girder spans	402.50
Riveting girder spans	264.00
Framing ties	130.75
Laying floor	222.25
Painting, first coat	204.37
Painting, second coat	180.25
Total labor	$2,521.00
Coal for derrick engine	120.00
Blacksmith coal	45.00
Train service, 5 days, at $25	125.00
Wear of tools	125.00
Total, 500 lin. ft., at $6	$2,936.00

Summary per ton—	Per ton.
General expense, $304	$0.90
Erecting and riveting, $1,479	4.32
Painting, 2 coats, $385	1.13
Framing and laying floor, $353	1.05
Total labor	$7.40
Coal, $165	0.48
Train service, $125	0.37
Wear of tools, $125	0.37
Grand total	$8.52

The cost of framing and laying the floor, it will be seen, was $353, or 70 cts. per lin. ft.

The total cost of this viaduct to the railway company was as follows:

Steel superstructure, labor	$ 4,240
Steel superstructure, materials	19,000
Masonry substructure, labor	4,360
Masonry substructure, materials	5,200
Total	$32,800

This is equivalent to $46.50 per lin. ft. for superstructure, and $19.10 per lin. ft. for substructure, or $65.60 per lin. ft. of viaduct. The substructure, therefore, cost 30% of the total. Since the steel superstructure weighed 340 tons, or 680,000 lbs., it cost 3.56 cts. per lb. in place. As previously stated, the average height of this viaduct was 63 ft.; its maximum height was 89 ft. from top of masonry to base of rail. It was supported by 6 towers (or 12 bents), the length of the "tower spans" being 31 ft. The remaining spans, or "open spans," were three spans of 57 ft., two of 38 ft., and two of 30 ft. The above costs for labor include contract price for erection, salaries of engineers, inspectors, etc. The costs for materials include freight and train service.

Cost of Erecting a 580-ft. Viaduct.—This viaduct was erected by contract, with the same gang as the 500-ft. viaduct just described. The weight of the steel was 382 tons, or 764,000 lbs. The profile area was 34,800 sq. ft., the average height was 60 ft., and the maximum height from masonry to base of rail was 89 ft. There were 7 towers or 14 bents. The "tower spans" were 31 ft. The "open spans" were: One 61-ft. span, three 57-ft., one 38-ft., and three 30-ft. spans.

The cost to the contractor was as follows:

Time traveling—

2 days at $5.00	$10.00
2 days at 3.50	7.00
12 days at 3.25	39.00
20 days at 3.00	60.00
Total	$116.00

Loading derricks and tools—

4 days at $5.00	$20.00
6 days at 3.25	19.50
10 days at 3.00	30.00
Total	$69.50

Erecting traveler—

1 day at $5.00	$5.00
1 day at 3.50	3.50
1 day at 3.25	3.25
10 days at 3.00	30.00
Total	41.75

Erecting towers—

11 days at $5.00	$ 55.00
10 days at 3.50	35.00
22 days at 3.25	71.50
104 days at 3.00	312.00
24 days at 2.75	66.00
5 days at 1.50	7.50
Total	$547.00

Riveting towers—

32 days at $3.25	$104.00
88 days at 3.00	264.00
8 days at 1.50	12.00
Total	$380.00

Filling bases of posts with concrete—

4 days at $2.75	$11.00

Erecting girder spans—

12 days at $5.00	$ 60.00
12 days at 3.50	42.00
24 days at 3.25	78.00
83 days at 3.00	249.00
6 days at 1.50	9.00
Total	$438.00

Riveting girder spans—

24 days at $3.25	$ 78.00
66 days at 3.00	198.00
9 days at 1.50	13.50
Total	$289.50

Floor, framing ties—

18 days at $4.00	$72.00
30 days at 3.00	90.00
10 days at 2.75	27.50
Total	$189.50

Laying floor—

15 days at $3.50	$ 52.50
48 days at 3.25	156.00
100 days at 3.00	300.00
Total	$508.50

Painting—first coat—

7 days at $5.00	$ 35.00
35 days at 2.75	96.25
25 days at 3.25	81.25
40 days at 3.00	120.00
Total	$332.50

Painting—second coat—

2 days at $5.00	$ 10.00
28 days at 3.25	91.00
60 days at 3.00	180.00
Total	$281.00

Summary—

Time traveling	$ 116.00
Loading derricks, etc.	69.50
Erecting traveler	41.75
General expense	$ 227.25
Erecting towers	547.00
Riveting towers	380.00
Filling bases	11.00
Erecting girder spans	438.00
Riveting girder spans	289.50
Floor, framing ties	189.50
Laying floor	508.50
Painting, first coat	332.50
Painting, second coat	281.00
Total	$3,204.25
Coal for derrick engine	72.00
Blacksmith coal	45.00
Train service, 5 days, at $25	125.00
Wear of tools	160.00
Grand total	$3,606.25

Summary of cost per ton—

	Per ton.
General expense, $227	$0.59
Erecting and riveting, $1,665	4.36
Painting, 2 coats, $603	1.60
Framing and laying floor, $698	1.83
Total	$8.38
Coal, $117	0.30
Train service, $125	0.33
Wear of tools, $160	0.42
Grand total	$9.43

Comparing this with the cost of erecting the 500-ft. viaduct, we see that the painting cost 50% more per ton, and that the work on the floor (timber deck) cost 80% more. In this 580-ft. viaduct the total labor on the deck cost $698, or $1.20 per lin. ft., which is fully double what it should have cost.

The total cost of this 580-ft. viaduct to the railway company was as follows:

Steel superstructure, labor	$ 5,750
Steel superstructure, materials	21,950
Masonry substructure, labor	5,860
Masonry substructure, materials	4,240
Total	$37,800

This is equivalent to $47.80 per lin. ft. for superstructure and $19.70 per lin. ft. for substructure, or $67.50 per lin. ft. of viaduct. Therefore the substructure cost 20% of the total. The steel superstructure cost 3.63 cts. per lb. in place.

Cost of a 1,170-ft. Viaduct.—This steel viaduct had profile area of 97,200 sq. ft., and an average height of 78½ ft. It had 12 towers and 2 "rocker bents," making a total of 26 bents. The extreme

height of bent from top of masonry pedestals to base of rail was 104 ft.; the average height 77 ft.; and the aggregate height of all bents, 2,000 ft. There were 12 plate girder "tower spans" of 31 ft. over the towers, 11 plate girder "open spans" of 61 ft., and 4 girder "open spans" of 31 ft.

The weight of the metal was 1,690,000 lbs.

The actual cost of erecting the viaduct was $8.50 per ton. The viaduct was built and erected by a contractor at the following cost to the railway company for materials and labor:

674,000 lbs. girder spans in place, at 3.9 cts....	$ 25,286
1,004,000 lbs. bents and towers, 3.9 cts..........	39,156
5,400 lbs. sheet lead, at 6 cts................	324
132,000 ft. B. M. in floor system, at $25........	3,300
Total superstructure........................	$ 68,066
1,000 cu. yds. dry excavation, at 40 cts........	4,000
640 cu. yds. wet excavation, at $2..........	1,280
216,000 ft. B. M. sheet piling, etc., in cofferdams, at $25	5,325
8,000 lin. ft. piles delivered and driven, at 30 cts.	2,430
3,000 cu. yds. riprap, at $1.50...............	4,500
1,800 cu. yds. concrete, at $8..................	14,400
1,800 lbs. iron in anchor bolts, etc., at 4 cts...	72
Total superstructure........................	$ 32,007
Engineering, shop inspection, etc.................	5,500
Grand total.....................................	$105,573

The cost per lin. ft. of viaduct was:

	Per lin. ft.	Per cent.
Superstructure	$58.13	64.3
Substructure	27.35	30.4
Engineering	4.77	5.3
Totals	$90.25	100.0

The foundations of two of the towers, eight masonry pedestals in all, were in water, which ran up the total cost of substructure very considerably. Nevertheless, the cost of the substructure of the majority of steel viaducts of large size is usually a far higher percentage of the total cost than it should be. This is due to the fact that bridge engineers are generally very painstaking in the economic design of superstructures and not so painstaking in the design of substructures. Because the design of a superstructure is an exact science, there is an attractiveness about such work easy to understand. Because the design of foundation is merely by rule of thumb, there is less of fascination in the work. This particular viaduct is a splendid example of our contention that engineers usually put altogether too little brains into designing substructures.

The concrete pedestals of the substructure rest on rock, with the exception of eight pedestals which have pile foundations. Yet every one of these concrete pedestals is designed exactly as if it were intended to rest on soft earth, as is shown in Fig. 15. It will be

seen that each pedestal has a base of 110 sq. ft. Even at a point where the viaduct is 90 ft. high, as in this case, the weight of the steel is less than 1,700 lbs. per lin. ft. The timber floor system would add only a little more than 300 lbs. per lin. ft., making a total of 2,000 lbs. Adding a live load of 5,000 lbs. per lin. ft. to this, we have 7,000 lbs. per lin. ft. Each bent has to support the weight of 45 lin. ft. of bridge, or $45 \times 7,000 = 315,000$ lbs. But this is distributed over two pedestals, making a load of 160,000 lbs. per pedestal, or 80 tons. If wind pressure were to raise this to 110 tons, the load on the foundation would be 1 ton per sq. ft., for we have 110 sq. ft. of foundation area.

From this it is clear that, even where resting on earth, the area of the pedestal base is in excess of any reasonable requirement.

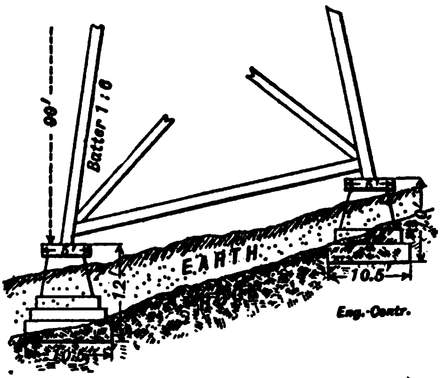


Fig. 15.—Pedestals for Steel Viaduct.

Reid's "Concrete and Reinforced Concrete Construction," p. 408, gives the safe bearing power of soft clay at 1 ton per sq. ft., and of ordinary loam at 3 tons. Hence the absurdity of providing any such area of base as in this pedestal under discussion, for it is resting not on earth but on rock. It is perfectly clear that the designer could have saved 60 or 70% of the concrete masonry in each of these pedestals, had he not followed a rule of thumb which is applicable only to foundations resting on earth, and not always applicable even to them.

It is no unusual thing for earth to be called upon to support 10 tons per sq. ft., and there are few places where 5 tons can not be safely imposed on each square foot. A bridge engineer who is seeking to effect every possible economy should visit the site of every large structure, and personally test the bearing power of the earth, by digging test pits to the proposed depth of foundation where possible.

Another noticeable economic defect in the design of these pedestals is the excavation of the rock so as to form a square footing. Solid rock having so slight a transverse slope as that shown in the illustration need not be excavated at all. A few drill holes, in which large dowel pins are placed, will serve every purpose in providing against possible sliding of the masonry on the ledge rock under the vibration of passing trains.

Cost of the Pecos Viaduct.*—The Pecos Viaduct, Texas, was built in 1891 for the Galveston, Harrisburg & San Antonio Ry. It is a single track steel viaduct 2,180 ft. long, and 321 ft. high at the center. The viaduct is built on a peculiar profile. For 1,070 ft. of the west end the average height of the viaduct is 57 ft., then the ground drops off precipitously, so that for a distance of 600 ft. the towers are 260 ft. high and rest on masonry piers, of varying heights up to 80 ft. Then the ground rises on an almost uniform slope to the last pier on the east end. The profile area between the base of rail, and the tops of masonry piers is approximately 280,000 sq. ft. Dividing this by the length gives 129 ft. as the average height of the viaduct. None of the tower piers is under water at times of low water, but three of them are submerged at times of high water. There are 33 towers and the tower spans are plate girders 35 ft. span. The spans between the towers are 8 riveted lattice girder spans of 65 ft., 2-pin-connected cantilever spans of 172 ft., and one 80 ft. suspended span. The masonry piers were built in 229 working days. The steel work was erected in 118 days, including 24 days required to build a traveler weighing 116 tons and 6 days to take it down and move it to the opposite side of the river. The erecting gang average 60 men and at no time exceeded 79. The average amount of steel erected were 41,000 lbs. per day for the 86 days, or 39,600 lbs. per day for the 118 days. If wages were $2.50 a day, this would be equivalent to 0.36 ct. per lb.; exclusive of the cost of erecting and moving the traveler, or 0.5 ct. per lb. including erecting and moving the traveler. The actual wages paid are not available but were apparently considerably more than $2.50, for the actual cost of erecting this viaduct was 0.87 ct. per lb. including not only the cost of erecting the traveler but the cost of the traveler itself.

The weight of this viaduct was as follows:

	Lbs.
34 plate girder spans, 35 ft. long........	495,550
1 plate girder span, 35 ft. long........	24,810
8 lattice girder spans, 65 ft. long......	354,120
1 lattice girder span, 80 ft. long.......	57,870
2 cantilevers, 172¼ ft. long...........	478,400
Floor bolts and railings................	51,620
Total superstructure	1,462,370
Towers and anchor bolts...............	2,147,190
Grand total	3,609,560

*Engineering-Contracting, Dec. 2, 1908.

The cost was as follows:

3,270 cu. yds. masonry, at $13	$ 42,505
3,609,560 lbs. steel delivered, at 4.43 cts.	160,000
Erecting, including cost of traveler	30,500
256,600 ft. B. M. timber flooring, at $20.75	5,325
Total	$238,330

This is equivalent to $119 per lin. ft.; and the weight of steel was 1,650 lbs. per lin. ft.

It will be noted that the masonry pedestals cost only 18% of the total cost of the viaduct.

Cost of the Marent Viaduct.*—In 1884 a single track iron viaduct was built for the Northern Pacific Ry. across Marent Gulch to replace a timber viaduct. The profile area of this viaduct is 95,700 sq. ft. below the top of the stringers, and the length of the viaduct is 800 ft., so the average height is practically $96,000 \div 800 = 120$ ft. nearly. It has two towers, each 200 ft. high; two towers each 120 ft. high; and four short bents.

There are 4 plate girder spans at the ends, each 30 ft.; 5 truss spans, each 116 ft. long; girders 23 ft. long over each of the four towers. The foundation piers are of concrete, of which there was 544 cu. yds. in all. The viaduct contained the following amount of iron and steel:

	Lbs.
Towers and bents	872,900
5 deck truss spans	466,700
Floor system	297,827
4 plate girder spans	40,161
Miscellaneous	8,962
Total, at 2,133 lbs. per lin. ft.	1,686,550

This is equivalent to 17.5 lbs. per sq. ft. of profile area.

The iron work cost 3.85 cts. per lb. delivered at St. Paul, and the "traffic charges" for transporting the iron and other materials from St. Paul, at 1 ct. per ton mile, amounted to $24,743.

The total cost was:

Foundations	$ 21,664.59
Masonry	30,079.81
Towers, materials and labor	49,188.44
Superstructure, materials and labor	36,593.94
Timber, floor	4,701.43
Painting	1,826.74
Permanent track	116.06
Engineering and incidentals	9,085.15
Permanent track	116.06
Total	$153,362.16
Traffic charges	24,743.18
Total, at $222.63 per lin ft.	$178,105.34

*Engineering-Contracting, Dec. 2, 1908.

The cost of erecting the towers was $15,800, and of erecting the superstructure (spans and floor) was $6,500, or a total of $22,300 for erecting 840 tons, or nearly $27 per ton. This exceedingly high cost is said to have been due to high wages and to working in the winter. It appears, however, to have been due to the usual laziness of men doing "company work."

The following were the quantities in the substructure, including the abutments:

	Cu yds.
Rock excavation	1,645
Earth excavation	3,689
Concrete	544
Cut stone masonry	722

It cost $7,664 to remove the old wooden viaduct, which contained 970,000 ft. B. M., or about $7.70 per M. for removing this timber.

Skilled labor received $3 to $4.50 a day. The cost of erecting and removing the temporary buildings in which the men lived was $2,700. Depreciation on plant was estimated at $4,500. Both these items are included above.

For comparison, the following weights of a viaduct of the same average height are given by Mr. H. G. Tyrrell. The weight of a single track railway viaduct 120 ft. high, with tower bents 30 ft. c. to c., and intermediate girder spans of 60 ft. was:

	Wt. per lin. ft.
Spans	622 lbs.
Bents	955 lbs.
Traction bracing	324 lbs.
Total	1,941 lbs.

Taking the cost of steel in place at 3½ cts. per lb. for girders and 4 cts. per lb. for bents and bracing, the cost per lin. ft. is $75 for the steel. To this must be added the cost of the concrete pedestal piers.

Cost of the Old Kinzua Viaduct.—Mr. Thomas C. Clark gives the following data relative to the original Kinzua viaduct built in 1882:

The viaduct was 2,050 ft. long, 302 ft. high at the center, and weighed only 1,400 tons, or 7.36 lbs. per sq. ft. of profile area. It was designed for a live load of an 80 ton consolidation engine followed by a train of 3,000 lbs. per lin. ft. Rough calculations from a small profile indicate that the profile area was about 380,000 sq. ft. below the base of rail. The viaduct was erected by a gang of 40 men in 4 mos., using one traveler. The iron work was delivered at only one end of the ravine, and slid down along a trough to a point below the traveler. The tower girders were 38½ ft. long, and the intermediate girders 61 ft. long. Mr. Clark claims that the first American viaduct was designed by C. Shaler Smith, the viaduct being really a high trestle with iron posts. Mr. Clark, in 1870, designed the first modern type of viaduct, consisting of braced towers supporting intermediate girders.

Mr. Clark states that the cost of erecting the Kinzua viaduct was less than $12 per ton, which is equivalent to $16,800 for erecting

the entire viaduct. This does not agree very well with his statement that 40 men erected it in 4 mos., for that would be about 4,000 man-days, and it is not likely that any such wages at $4 a day were paid, unless the height at which the men worked led to a demand for high wages. If wages averaged $2.50 a day, the labor cost would have been about $7 per ton. As a matter of fact this same viaduct was removed in 1900 and a new one built in its place, the cost of erection (including removal of the old viaduct) being given below.

Cost of the New Kinzua Viaduct.—Mr. C. R. Grim gives the following data about the Kinzua viaduct on the Erie R. R., in McKean County, Pa. It was built in 1900 to replace an iron viaduct built 19 years before. The viaduct is 2,053 ft. long, rests on the old piers, and has 20 towers, ranging from 30 to 285 ft. high from masonry to base of rail, and has a profile area of about 380,000 sq. ft. below the base of rail.

The weight of the deck spans is 638 tons, and that of the towers is 2,715 tons, total 3,353 tons. Two travelers were used, working from opposite ends. Each traveler spaned a clear space of 160 ft., having an old tower in the middle. The work of removing the old viaduct and erecting the new one consumed 4 mos., with a force of about 120 men at 10 hrs. a day. Charging the entire cost against the new viaduct, and assuming that wages averaged $2.50 a day, the labor cost would be about $30,000 or $9 per ton. The weight was about 17.6 lbs. per sq. ft. of profile area.

Weight of a Steel Viaduct.—A single track steel viaduct was built in 1904 near Paoli, Ind., for the Chicago, Indianapolis & Louisville Ry. It is 870 ft. long, and 87 ft. high in the center. It has 2 abutments and 36 small pedestal piers, four under each tower. The abutments are 60 ft. high. The pedestal piers are 3½ ft. square on top and extend down to solid rock, a distance of 3 to 12 ft. below the ground. There are 4,300 cu. yds. masonry in piers and abutments, and 1,091,000 lbs. steel and cast iron in the viaduct.

Data on Riveting a Viaduct.—In the construction of the Cuyahoga Valley Viaduct, there were 18,869 seven-eighths inch rivets driven in the field. The average day's work for a gang of 4 men was 192 rivets. The best day's work was 315, all hand driven. The defective rivets amounted to less than 2 per cent.

Cost of Concrete Pedestals for a Steel Viaduct.—The viaduct was 410 ft. long with towers 30 ft. high on the Canadian Northern Ontario Ry. The concrete work consisted of 10 x 10 x 4-ft. footings carrying pedestals 5 x 5 ft. on top with sides battered 1 in 12 to meet the footings. The tops of the pedestals were all at the same elevation but their height varied, the highest being 18 ft. above tops of footing. The pedestals were cored for anchor bolts. The total amount of concrete in the work was 711½ cu. yds., of which 298½ cu. yds. were in the footings and 405 cu. yds. were in the pedestals. The concrete was a 1-2½-4 mixture, taking 1 1/2 bbls. cement for the footings; and a 1-2¼-4 mixture, taking 1¼ bbls. cement for the pedestals. Altogether 3,350 bags of cement were

used for the 711½ cu. yds. of concrete, including 44 bags for the 1-2 mortar top dressing and 15½ bags for washing, plastering, etc.

Excavation.—The pits for the footings were 12 ft. square carried down into hard clay through 5 or 6 ft. of sand and clay and a 1-ft. layer of driftwood. The average depth of pit was 11½ ft., the maximum depth 15.2 ft. The material was handled by a horse-power derrick, consisting of a guyed mast and a boom set at 45°. The bucket was lifted by a double purchase block, the fall of the line being carried to a pulley set a few feet to one side of the mast and thence to a whiffletree. This gave enough side pull on the boom to swing the bucket clear of the excavation. To hold the boom fixed during hoisting and lowering, a line from the end was carried to the far side of the excavation and operated by one man. One man drove the horse. Two ¼-cu. yd. buckets were employed, one being filled as the other was being dumped. There were 1,127 cu. yds. of excavation which cost as follows:

Items.	Total.	Per cu. yd.
General expenses	$194	$0.172
Foreman, 35 days at $3	105	0.093
Labor, 323 days at $1.60	517	0.458
Horse, 26 days at $2	52	0.046
Totals	$868	$0.769

Forms.—The forms for the footings were rough 2-in. lumber braced to the pit walls. The pedestal forms were made of 2-in. dressed lumber. Five sets were made. Each form was made 16 ft. high and was added to at the bottom for the taller pedestals and cut off for the shorter pedestals, which were built last. Two sides of each form were built in panels or units, and the two other sides were built up board by board as the concreting progressed. The solid panel sides were held together by two wire ties every 3 ft. in height; one tie every 3 ft. held the other two sides. These ties were No. 9 gage wire looped around studs and tightened by twisting. There were also core forms for the anchor bolts, each a box 4 ft. long, 6 ins. square on top and 5½ ins. square on the bottom. The cost of the forms was as follows:

Lumber—	Total.	Per cu. yd.
7,000 ft. B. M. 2-in. derrick at $19 per M	$133	
2,000 ft. B. M. 2-in. rough at $18 per M	36	
750 ft. B. M. 2x4-in. scantling	14	
Cartage, $2.50 per M. ft	24	
Anchor bolt boxes, etc.	10	
Totals	$217	
Deduct salvage $10	$207	$ 0.29
Wire, Ties, Nails—		
5 rolls No. 9 at 3 cts	$ 12	
200 lbs. wire nails at $2.50	5	
Totals	$ 17	$0.024

Labor—		
Carpenter, 28 days at $2.50	$ 70	
Helpers, 38 days at $1.75	67	
Totals	$137	$0.193
Grand totals	$361	$0.507

Concrete.—The concrete was mixed by hand on "boards" set close to the piers and was shoveled directly into the forms. The materials were transported to the boards in wheelbarrows. A gang of 1 foreman, 5 barrowmen, 6 mixers and 1 man in the form averaged 25½ cu. yds. per day, or a little over 2 cu. yds. per man working. The maximum day's work was 38 cu. yds. with 16 men. The concrete was deposited moderately wet and the mortar was spaded to the surface. The top 3 ins. of the pedestals was built of 1-2 mortar. The exposed surface of the piers was washed with a thin cement grout; about 1 bag of cement was required for 25 sq. yds. of surface. One man covered 7½ sq. yds. per hour, using an ordinary whitewash brush. The cost of the concrete work was as follows:

Materials—	Total.	Per cu. yd.
173 cu. yds. rubble stone at $0.85	$ 147	$ 0.207
555 cu. yds. 2-in. stone at $1.875	1,041	1.463
290 cu. yds. sand at $1.25	363	0.510
840 bbls. cement at $1.80	1,512	2.121
Cartage at 15 cts. per bbl	126	0.163
Totals	$3,190	$ 4.464
Labor—		
Foreman, 28 days at $4	$112	$ 0.157
Laborers, 343 days at $1.75	600	0.843
Totals	$712	$ 1.000

General Expenses.—General expenses were as follows:

Superintendence	$239.50
General labor	78.40
Interest and depreciation on plant tools	70.50
Total	$388.40

This gives a charge of 27.3 cts. per cubic yard of concrete.

There were also the following items of cost:

24 M. ft. B. M. 6x8-in. hemlock at $20	$480
Labor backfilling piers	162
Platforms, runways, etc	69
Total	$768

We can summarize the cost of concrete work as follows:

	Per cu. yd.
General expenses (⅓ of $388)	$0.273
Platforms, runways, etc.	0.097
Forms	0.507
Labor	1.000
Materials	4.464
Total	$6.341

Mr. J. H. Ryckerman is authority for the above data.

Cost of Abutments and Pedestal Piers, Lonesome Valley Viaduct.—Mr. Gustave R. Tuska gives the following on the concrete substructure of the Lonesome Valley Viaduct, near Knoxville, Tenn. There were two U-shaped abutments and 36 concrete pedestal piers made of a light limestone that deteriorates rapidly when used for masonry. Derricks were not needed as would have been the case with masonry piers, and colored labor at $1 for 11 hrs. could be used. The piers were made 4 ft. square on top, from 5 to 16 ft. high, and with a batter of 1 in. to the foot. The abutments average 26 ft. high, 26 ft. long on the face, with wing walls 27 ft. long; the wall at the bridge seat is 5 ft. thick, and the wing walls are 3½ ft. wide on top. Batters are 1 in. to the foot.

The forms were made of 2-in. tongued and grooved plank, braced by posts of 2 x 10-in. plank placed 3 ft. c. to c. for the abutments, and at each corner for the piers. At the corners one side was dapped into the other, so as to prevent leakage of cement. The posts were braced by batter posts from the earth. For the piers a square frame was dropped over the forms and spiked to the posts. The abutment forms were built up as the concreting progressed. The north abutment forms were made in sections 6 ft. high, held by ¾-in. bolts buried in the concrete. The lower sections were removed and used again on the upper part of the work, thus saving plank. The inside of forms was painted with a thin coat of crude black oil. The same form was used for several piers.

The concrete was 1 : 2 : 5, the barrel being the unit of measure, making about ¾ cu. yd. of concrete per batch. The mortar was mixed with hoes, but shovels were used to mix in the stone. By passing the blade of a shovel between the form and the concrete, the stone was forced back and a smooth mortar face was secured. Rammers weighing 30 to 40 lbs. were used for tamping. Two days after the completion of a pier the forms were removed. The concrete was protected from the sun by twigs, and was watered twice a day for a week. It was found by actual measurement that 1 cu. yd. of concrete (1:2:5), the ingredients being measured in barrels, consisted of 1¼ bbls. of Atlas cement, 10 cu. ft. of sand and 26½ cu. ft. of stone. The total amount of concrete was 926 cu. yds. of which two-thirds was in the two abutments. The work was done (in 1894) by contract, for $7 per cu. yd., cement costing $2.80 per bbl., sand 30 cts. per cu. yd., and wages $1 a day. A slight profit was made at this price. A gang of 15 men and a foreman would mix and lay about 40 cu. yds. in 11 hrs. when not delayed by lack of materials. The cost of making the concrete, with wages at $1 a day, was:

	Cents per cu. yd.
1 man filling sand barrels and handling water......	2.7
2 men filling rock barrels	5.4
4 men mixing sand and cement....................	10.6
4 men mixing stone and mortar....................	10.6

	Cents per cu. yd.
2 men wheeling concrete	5.3
1 man spreading concrete in place	2.7
1 man tamping	2.7
Total labor	40.0
1 foreman at $2	5.0
Total exclusive of forms	45.0

If wages had been $1.50 a day instead of $1, the labor cost would have been 68 cts. per cu. yd.

Cost of Paint.—Mr. Walter G. Berg, Chief Engineer of the Lehigh Valley R. R., gives the following on painting iron railway bridges:

Oxide of Iron.

6¼ lbs. oxide of iron, at 1 ct.	$0.06
5/6 gal. (6¼ lbs.) raw linseed oil, at 56 cts.	0.47
Cost of 1 gal. of paint	$0.53

Red Lead.

20 lbs. red lead, at 5 cts.	$1.00
¾ gal. (5½ lbs.) raw linseed oil, at 56 cts.	0.42
Cost of 1 gal of paint	$1.42

Graphite.

3¾ lbs. graphite paste, at 12 cts.	$0.45
¾ gal. boiled linseed oil, at 59 cts.	0.45
Cost of 1 gal. of paint	$0.90

Weight and Surface Area of Steel Bridges.—Mr. C. E. Fowler, Chief Engineer Youngstown Bridge Co., gives a table of the weights of iron highway and single track bridge trusses, and the corresponding areas of metal requiring painting, as determined "by actual calculation in a large number of cases." I find by a study of the tables that they can be very simply expressed in rules or formulas, as follows: For a highway bridge divide the weight of metal in pounds by 7 to get the area of metal surface in square feet. This applies to highway bridges 16 ft. wide, calculated for a floor load of 90 lbs. per sq. ft., for all spans from 40 to 300 ft. For a single track railway bridge, divide the weight of metal in pounds by 12 to get the area of metal surface in square feet.

The weight in pounds of metal in a highway bridge is found by adding 50 to 2 times the span in feet and multiplying this sum by the span in feet. Expressed in a formula this rule is $w = L(2L + 50)$.

The weight in pounds of metal in a single track railway bridge is found by adding 400 to 4.8 times the span in feet and multiplying this sum by the span in feet. $w = L(4.8L + 400)$.

Cost of Painting a Howe Truss Bridge.—The bridge was painted with two coats of paint costing $1 per gallon. One gallon covered 133 sq. ft., two coats thick, and a painter averaged 166 sq. ft., two

coats thick, per 10 hrs., or 332 sq. ft. of one coat per day. The cost was, therefore, as follows:

	Cts. per sq. ft.	Cts. per sq. yd.
Paint, two coats	0.75	6.8
Labor painting, two coats (17½ cts. per hr.)	1.15	10.3
Total	1.90	17.1

Cost of Painting 6 R. R. Bridges.—Three spans pin-connected Pratt truss bridges, each 145 ft. long, 14 ft. wide and 20½ ft. high, were painted with one coat at a cost of $48 per span for labor. One span required 35 gals. of asphaltum paint costing 65 cts. per gal. The other spans received 27 gals. of carbon paint each, at $1.50 per gallon.

A riveted Pratt truss bridge, 94 ft. long, 14 ft. wide and 20 ft. high was given one coat of black carbon paint, 23 gals., at $1.50 per gal. The labor was $40.

A double-intersection riveted lattice truss bridge, 96 ft. long, 14 ft. wide and 20 ft. high, was repainted with one coat of carbon paint, 26 gals., at $1.50 per gal. The labor cost $46.

A single intersection lattice truss highway bridge (20-ft. roadway and two 8-ft. sidewalks), 106 ft. long, was painted with one coat of black carbon paint, 35 gals., at $1.25 per gal. The labor cost $59.

Cost of Painting 6 R. R. Bridges and 2 Viaducts.—Mr. O. E. Selby, in Trans. Am. Soc. C. E., 1897, has a paper on the cost of painting the Louisville and Jeffersonville Bridge across the Ohio River. The work was begun June 3, and finished Aug. 7, 1895. There was practically no traffic over the bridge during the work, which, of course, lessened the cost of painting; and the iron being new required no great amount of cleaning. The force averaged about 50 men with 1 foreman, 1 assistant foreman and 1 timekeeper. The men were mostly ordinary bridge men, erectors and carpenters, and were paid $2 a day of 10 hrs. Some few men painting sidewalk railings and other parts not hazardous were paid $1.50 a day. The paint was oxide of iron, and was used just as it came from the barrel, except for a little occasional thinning, equivalent to about ½ gal. per bbl. of paint. The cost of the paint was 67 cts. per gal. The best results were obtained with flat brushes costing $7.50 per doz., of which 19 doz. were used; 4 doz. steel brushes and 13 doz. whisk brooms were used for cleaning the iron. The total cost of the work was: Paint, $3,769; labor, $4,427; equipment, $301; accident insurance, $200; total, $8,697 distributed as follows:

Jeffersonville Approach (Viaduct) and Span No. 1 (4,271 Ft. Long; 1,762 Tons).

	Per ton.
0.62 gallon iron oxide paint	$0.42
Labor, $2 per 10 hrs.	0.51
Total per ton of 2,000 lbs.	$0.93
Total per lin. ft.	$0.38

This Jeffersonville approach is a viaduct having an average height of 40 ft. and a length of 4,063 ft., all single track, except 1,000 ft., which is double track. Span No. 1 is single track, 209 ft. c. to c. The Jeffersonville approach had previously been painted with one coat in October, 1892. The work of which costs are above given consisted in going over the viaduct, cleaning and painting all spots where rust had formed; then after this had dried the whole viaduct was given one coat.

Louisville Approach (2,585 Ft. Long; 1,012 Tons). Per ton.

	Per ton.
0.90 gallon paint, first coat	$0.61
0.58 gallon paint, second coat	0.39
Labor on first coat	0.72
Labor on second coat	0.38
Total per ton	$2.10
Total per lin. ft	$0.82

This Louisville approach is 2,585 ft. long, single track, and has an average height of 45 ft. It had been erected a year before it was painted, and had never been painted before. It received two coats throughout.

Bridge Spans Nos. 5 and 6 (Each 338 ft. c. to. c.; Total Weight 665 Tons). Per ton.

	Per ton.
0.66 gallon paint, first coat	$0.44
0.44 gallon paint, second coat	0.30
Labor on first coat	0.47
Labor on second coat	0.35
Total per ton of 2,000 lbs	$1.56
Total per lin. ft	$1.53

Bridge Spans Nos. 2, 3 and 4 (Each Span 546½ ft. c. to c.; Total 2,768 Tons). Per ton.

	Per ton.
0.50 gallon paint, first coat	$0.33
0.32 gallon paint, second coat	0.22
Labor on first coat	0.32
Labor on second coat	0.22
Total per ton of 2,000 lbs	$1.09
Total per lin. ft	$1.84

All these bridge spans were single track, erected about a year before they were painted. All the iron had had a shop coat of linseed oil. All the spans were given two coats of paint throughout, except the inside of the top chords and end posts which received only one coat, as it was believed that this one coat in such a protected location would outlast the two coats on exposed work.

Spans Nos. 5 and 6 were erected in the latter part of 1893, while the other and longer spans were erected a year later, so that the rustier condition of Nos. 5 and 6 may account for their taking more paint.

The labor cost of painting 5,700 lin. ft. of sidewalk railings was $390, or $6.85 per 100 ft. This does not include the cost of the paint, which was a small item. Half of this railing was a lattice railing 4 ft. high; the other half was a gas pipe railing consisting of two lines of 1¼-in. gas pipe.

Cost of Painting 50 Plate Girder Bridges.—Mr. W. J. Wilgus gives the following data on the cost of repainting 33 steel bridges on the Rome, Watertown & Ogdensburg R. R. in 1896-8. The bridges were originally painted with two coats of "patent paint" that had failed within a year. The following costs include cleaning with wire brushes, and repainting with one coat of asphaltum-varnish paint made of 4 lbs. lampblack ground in pure raw linseed oil, ⅞ gal. genuine asphaltum varnish, ¼ gal. pure boiled linseed oil, and ¼ gal. drying japan. This paint cost 60 to 80 cts. per gal., and 1 gal. covered 350 sq. ft. Labor cost $2 a day.

The calculation of the exposed areas of many of the plate girder bridges showed that there were 100 sq. ft. for every ton of 2,000 lbs.

Cost of Painting 50 Plate Girder Spans (Av. Length, 74 ft.; Total Weight, 1,884 Short Tons).

	Per ton.
0.30 gal. paint	$0.175
Labor cleaning and painting	0.340
Total per ton	$0.515

Cost of Painting 5 Truss Spans (Av. Length, 155 ft.; Total Weight, 638 Tons).

	Per ton.
0.39 gal. paint	$0.235
Labor cleaning and painting	0.490
Total per ton	$0.725

Cost of Painting 11 Spans of a Viaduct (Total Length, 706 ft.; Height, 88 ft.; Weight, 342 Tons).

	Per ton.
0.48 gal. paint	$0.39
Labor cleaning and painting	0.60
Total per ton	$0.99

Cost of Cleaning and Painting 10 Bridges.—Mr. E. D. Graves gives the following data on the painting of light double triangular trusses in bridge spans from 80 to 136 ft., the total length being 1,000 ft. painted in the summer of 1897. The steel work had received one shop coat of iron oxide paint, and had been in place one year. The greater part of the surfaces was found to be scaled off and rusted. The surfaces were scraped with a steel scraper or brushed with a steel wire casting-brush. The dust was removed with a whisk broom, and one coat of No. 38 Detroit Graphite paint applied, costing $1.10 per gallon, delivered. The floor beams and bottom chords being most likely to rust, were painted a second coat. The foreman received $3.50 per day, and had 8 to 12 men, at $1.75. These men were mostly laborers, except a few bridge men for the top work. The cost was as follows per ton of 2,000 lbs.:

Cost of First Coat—	Per ton.
0.94 gal. first coat on 202 tons	$1.04
Labor cleaning and painting 202 tons	1.44
Total per ton, one coat	$2.48

Cost of Second Coat (Bottom Chord and Floor Beams).

	Per ton.
0.35 gal. second coat on 100 tons	$0.38
Labor painting second coat 100 tons	0.58
Total per ton of bottom chord and beams	$0.96

The total cost of paint and labor was $598, or nearly 60 cts. per lin. ft. of bridge.

Cost of Painting 48 Bridges and 2 Viaducts.—Mr. C. D. Purdon gives the following data: These bridges were new and painted with two coats of red lead. They had received one coat of oil at the shop.

	Cost per ton		
	Paint.	Labor.	Total.
Two deck girders, each 54 ft. (34.3 tons)	$0.80	$1.34	$2.14
Pratt truss, 103 ft. (62.9 tons)	0.58	1.45	2.03
Pratt truss, 180 ft. (161.4 tons)	0.82	1.27	2.09
Six deck girders, each 54 ft. (105.2 tons)	0.65	1.12	1.77
Iron viaduct; two 64 ft., two 48 ft., and two 32 ft. deck girders (182.4 tons)	1.40	0.76	2.16
Iron viaduct, eight 64 ft., and seven 32 ft. spans (471 tons)	1.00	0.66	1.66
Pratt truss, dbl. track, 150 ft. (228.7 tons)	0.51	1.17	1.68

The summary of the amount of lead and oil used on the above bridges is as follows:

	Per ton	
	Lbs. of lead.	Gals. of oil.
Deck girders (139.5 tons)	6.08	0.48
Single track trusses (224.3 tons)	7.12	0.56
Viaducts (653.3 tons)	13.80	0.44
Summary of all (1,245.6 tons)	10.10	0.42

Judging from the amount of paint used, a truss bridge takes 1.2 times as much paint per ton as a plate girder, and a viaduct takes 2.3 times as much as a plate girder. This is confirmed on p. 560.

The cost of cleaning and painting 17 spans over the Arkansas River is as follows: These bridges received two coats of red lead and oil, having been originally painted with iron oxide which was first cleaned off. The cost of cleaning off the old paint is included, and almost equaled the cost of applying the first coat of red lead.

Cost of 9 Spans (153 Ft.; Weight, 810.6 Tons).

	Per ton.
7 lbs. red lead	$0.49
Labor	0 58
Second coat—	
2.3 lbs. red lead	0.17
Labor	0.25
Total per ton	$1.49

Cost of 8 Spans (Three, 253 Ft.; Four, 162 ft.; One Draw, 370 Ft.; Total Weight, 1,451.2 Tons).

	Per ton.
First coat—	
6 lbs. red lead	$0.42
Labor	0.54
Second coat—	
1.9 lbs. red lead	0.15
Labor	0.26
Total per ton	$1.37

The average of the above 17 spans was: 6.42 lbs. of lead and 0.23 gal. of oil per ton for the first coat; 2.04 lbs. of lead and 0.074 gal. of oil per ton for the second coat.

The cost of repainting 13 spans with two coats of iron oxide was as follows:

	—Gallons—		——Cost per ton——		
	Paint.	Oil.	Paint.	Labor.	Total.
200-ft. deck truss and two 50-ft. girders, dbl. track (475.6 tons)	128	60	$0.20	$0.62	$0.82
Pony lattice, 92½ ft. (115 tons)	30	10	0.31	0.33	0.64
Three through spans, 150 ft. and 302 ft. draw span (656.7 tons)	335	122	0.36	0.63	0.99
Three through spans, 150 ft. (313.3 tons)	184	46	0.38	0.54	0.92
Three through spans, 150 ft. (297.6 tons)	130	30	0.28	0.54	0.82

These 13 spans had originally been painted with iron oxide which was not cleaned off except at rusted spots.

It will be noted that about ⅓ gal. of oil was used to thin each gallon of paint.

The cost of repainting ten old bridges with one coat of iron oxide was as follows:

	—Gallons—		——Cost per ton——		
	Paint.	Oil.	Paint.	Labor.	Total.
Double track truss, 126 ft. (176 tons)	75	25	$0.19	$0.55	$0.74
Through plate girder, 50 ft. (27.6 tons)	15	3½	0.34	0.34	0.68
Six spans deck truss, 150 ft. (696.5 tons)	280	62	0.25	0.51	0.76
Deck plate girder, 70 ft. (30.4 tons)	12	..	0.20	0.22	0.44
Through plate girder, 47 ft. (24.5 tons)	17	..	0.32	0.34	0.66

These 10 spans had been originally painted with iron oxide which was not cleaned off except at rusted spots.

It will be noted that the average of these ten spans is 0.51 gal. of paint and oil per ton, for one coat work.

Cost of Cleaning and Painting Four Bridges, St. Louis.—Mr. N. W. Eayers gives the following data on painting railway bridges with one coat of carbon paint. This paint was ground especially for the bridge work, and came as "semi-liquid" taking about 1 gal. of oil to 1 gal. of "semi-liquid." It was laid on thick.

The St. Louis Merchants' Bridge is double track, three spans, each of 517½ ft., trusses 75 ft. deep at center. It was erected in 1890, and had had one shop coat and one coat of iron oxide after

erection. The metal was very rusty, and the cost of cleaning was quite large, but could not be separated from the cost of painting. The total cost of cleaning and painting these three spans in 1895 was as follows:

493¼ gals. boiled oil, at $0.58	$ 286.08
552½ gals. carbon paint, at $1.25	690.62
Sundry supplies	69.96
48 days' labor, at $2.50	120.00
91.4 days' labor, at $2.25	205.65
444.4 days' labor, at $2.00	888.80
51.5 days' labor, at $1.00	51.50
Total	$2,312.61

The cost per lin. ft. was, therefore, $1.49, and 0.69 gal. of paint, costing 93.3 cts. per gal., was required per lin. ft.

The Ferry St. Bridge is a double track deck span, 126 ft. resting on iron columns. It was cleaned and painted in 1895, at the following cost:

32 gals. boiled oil, at $0.58	$ 18.56
22 gals. carbon paint, at $1.25	27.50
Labor	97.70
Total, at $1.14 per lin. ft.	$143.76

The Angelica St. Bridge is a through plate girder bridge, 68-ft. span, having a total painted surface of 6,250 sq. ft., which required 1 gal. of paint for every 312½ sq. ft. The cost was as follows:

10 gals. boiled oil, at $0.58	$ 5.80
10 gals. carbon paint, at $1.25	12.50
Labor	22.00
Total, at $0.59 per lin. ft.	$40.30

The Elevated Structure, Merchants' Bridge, consists of steel columns supporting plate girder spans of 28 to 35 ft., carrying a double track railroad. It was erected and painted in 1890, but in 1897 it was badly rusted and was repainted at a contract price of 57 cts. per ft. for 4,075 ft. The actual cost to the contractor was as follows:

Carbon paint and oil, one coat	$ 748.13
Labor for cleaning	657.67
Labor for painting	628.74
Total, exclusive of foreman's time	$2,034.54

The St. Louis (Eads) Bridge was repainted in 1896. It consists of three arched spans of a total length of 1,524 ft., carrying a double track railway on the lower floor and a highway on the upper floor. The floor beams for the highway are the struts for the wind truss. The bridge is 54 ft. wide out to out. The metal was quite rusty, in places, requiring chipping to remove scale, especially the highway floor beams exposed to locomotive smoke. It

was painted with one coat. The cost was $0.70 per ton distributed as follows:

675 gals. boiled oil, at $0.35	$ 236.25
650 gals. carbon paint, at $1.25	812.50
Sundry supplies	52.55
Labor, 130 days, at $2.50	325.00
246 days, at $2.25	553.50
955 days, at $2.00	1,910.00
Total, at $2.55 per lin. ft.	$3,889.80

Cost of Painting Two Railway Bridges.—The following data on scraping and painting two railway bridges are given by Mr. A. S. Markley. The bridges were both painted in 1896, bridge No. 1 being painted during the summer and bridge No. 2 during October and November. The structures are viaducts with lattice columns and lattice struts in towers. The total number of tons of iron in bridge No. 1 was 719; in bridge No. 2 there was 154 tons of iron.

Bridge No. 1, first coat—

	Total.	Per ton iron.
Red lead, 3,560 lbs., at $.049	$174.44	$0.242
Boiled oil, 177 gals., at .40	70.80	.098
L. black, 18 lbs., at .085	1.53	.002
Labor	558.39	.776
Total	$815.16	$1.118

Bridge No. 1, second coat—

Red lead, 2,395 lbs., at $.049	$117.35	$0.163
Boiled oil, 160 gals., at .40	64.00	.089
L. black, 55 lbs., at .085	4.67	.006
Labor	372.08	.517
Total	$558.10	$0.775

Bridge No. 2, first coat—

Red lead, 500 lbs., at $.049	$ 24.50	$0.159
B. L. oil, 18½ gals., at .40	7.40	.048
L. black, 5 lbs., .085	.43	.003
Labor	121.41	.788
Total	$153.74	$0.998

Bridge No. 2, second coat—

Red lead, 335 lbs., at $.049	$ 16.41	$0.106
B. L. oil, 17 gals., at .40	6.80	.044
L. black, 10 lbs., at .08½	.85	.005
Labor	89.90	.584
Total	$113.96	$0.739

Summary—

	Per ton iron. Bridge 1.	Bridge 2.
Labor	1.294	1.372
Labor and material	1.896	1.731
Material	$0.602	$0.359
Labor, scraping	.194	....
Labor, painting, first coat	.776	.788
Labor, painting, second coat	.517	.584
Pounds of red lead, first coat	4.95	3.25
Pounds of red lead, second coat	3.33	2.17
Gallons boiled oil, first coat	.246	.120
Gallons boiled oil, second coat	.222	.110

Cost of Painting Plate Girders, Truss Bridges and Trestles on the C. & W. M. Ry.*—Table XIX gives the cost of painting several bridges on the Chicago & West Michigan Ry. (Detroit, Lansing & Northern R. R.), the work being done in 1894.

Cost of Painting, Cross-References.—For further data consult the index under "Painting."

Cost of Bridge Abutments.—Mr. W. A. Rogers gives the following data relative to the construction of bridge abutments on the C., M. & St. P. Ry.: The work consisted in building 20 abutments for 10 four-track plate girder bridges over street crossings in Chicago. The work was done between May 1 and Oct. 1, 1898, in which time 8,400 cu. yds. of concrete were placed, all the work being done by company labor. The forms were made of 2-in. plank and 6 x 6-in. posts bolted together at the top and bottom with ¾-in. rods. The lumber was used over and over again. When the dressed plank became too poor for the face it was used for the back. The concrete was 1 Portland cement, 3 gravel and 4 to 4½ limestone (crusher run up to 3-in. size.) A mortar face 1½ ins. thick was built up with the rest of the concrete. The concrete was made quite wet, and each man ramming averaged 18 cu. yds. a day rammed. The concrete was mixed by a machine of the Ransome type, operated by a 12-hp. portable gasoline engine. The load was very light for the engine, and 8 hp. would have been sufficient. The engine made 235 revolutions per minute, and the pulley wheels were proportioned so that the mixer made 12 revs. per min. One gallon of gasoline was used per hour, and the mixing was carried on day and night so as not to give the concrete time to set. The time required for each batch was 2 to 3 mins., and about ½ cu. yd. of concrete was delivered per batch. The average output was 70 cu. yds. per 10-hr. shift, with a crew of 28 men; but as high as 96 cu. yds. were mixed in 10 hrs. The concrete was far superior to hand mixed concrete. The water for the concrete was measured in an upright tank and discharged by a pipe into the mixer. The sand and stone were delivered to the mixer in wheelbarrows, and the concrete was taken away in wheelbarrows. No derricks were used at all. Each wheelbarrow of concrete was raised by a rope passing over a pulley at the top of a gallows frame; one horse and a driver serving for this raising.

**Engineering-Contracting,* June 13, 1906.

TABLE XIX.—COST OF PAINTING BRIDGES.

Bridge.	Kind of Bridge.	Sq. yds. of Surface.	Weight in lbs.	Cost of Material.	Cost of Labor.	Total Cost.	Cost Per Sq. Yd.	Cost Per Ton.	No. lbs. Graphite.	Gals. Oil.
No. 150 7-10	—Plate Girder	100	11,700	$3.59	$7.07	$10.56	$0.10½	$1.80	20	3½
No. 121 2-10	—Plate Girder	80	8,436	2.85	6.00	8.85	.11	2.10	16	2¾
No. 224 6-10	—Plate Girder	172	22,873	8.10	14.47	22.57	.13 1-10	1.97	35	4
Belding	—Plate Girder	65	8,500	5.00	7.87	12.87	.20	3.00	20	4
*Huron River	—Dick Warren	800	84,950	19.80	48.21	68.01	.08½	1.72	90	14
†St. Joseph	—Overhead	710	73,729	20.99	59.00	79.99	.11¼	2.16	85	13
**Plymouth	—Iron Trestle	1,680	......	59.76	141.57	201.33	.12	....	260	40
††Ionia	—Lattice Girder	265	44.324	12.05	24.52	36.57	.14	1.65	50	9
Redford	—Through Pratt	...	101,825	24.94	65.51	90.45	...	1.85	110	15

* New; required no cleaning. † Highway Pratt. ** 30-ft. girders. †† New.

A small gasoline hoisting engine would have been more satisfactory than the horse which was worked to its full capacity. After the barrows were raised (12 ft.), they were wheeled to the abutment forms and dumped. The empty wheelbarrows were lowered by hand, by means of a rope passing over a sheave and provided with a counterweight to check the descent of the barrow. The cost of the concrete (built by company labor) was as follows:

	Per cu. yd.
Cement, gravel and stone delivered	$3.28
Material in forms (used many times)	.11
Carpenters building and taking down forms	.34
Labor	1.18
Total per cu. yd.	$4.91

The labor cost includes moving the plant from one bridge to the next, building runways, gasoline for engine, oil for lights at night, and unloading materials as well as mixing, delivering and ramming the concrete. Wages were $1.75 per 10-hr. day for laborers and $2.50 for carpenters.

Data on Thirty-two Concrete and Reinforced Concrete Bridges (20 Highway and 12 Railway), Including Yardage, Cost, Etc.*—An engineer is frequently called upon to estimate the probable cost of a bridge before plans are drawn for the structure. In such cases it is very desirable to have at hand the cost of several similar structures as a guide to the judgment. It is also desirable to have a short description of each structure, and a statement of the quantities of material involved in its construction. With such data at hand an engineer, even though somewhat inexperienced, is not likely to go far wrong in his preliminary estimate of cost—his reconnaissance estimate, if you choose to call it so.

Valuable as such records of cost are for the purpose just indicated, they possess an additional value that should not be underrated—namely, as a guide in comparing the relative economy of the designs of two similar bridges. For this latter purpose it is desirable to have a record not merely of the total yardage of concrete in each bridge, but the distribution of that yardage in the various parts of the bridge. The yardage in the arch ring, the yardage in the spandrel walls, the yardage in the abutments, and so on, should be given, together with the weight of steel reinforcement in each of these groups of concrete yardage. Unfortunately, however, the published records of concrete bridges are almost invariably lacking in this respect, as will be noted in the following records.

In this connection, a word as to what every record should contain. The following dimensions should be given: The total length of the bridge over all, total length between abutments, length of barrel or true width of bridge, width of floor surface, width of road way or carriage way, width of side walks, clear span of arch and rise, thickness at crown and at spring line, height of abutments and piers up to the spring line, width of piers at spring line,

*Engineering-Contracting, Sept. 2, 1908.

width of abutments at base, height of roadway above crown of arch, and ditto above low water.

When these dimensions are given, accompanied by a general description of the type of bridge and a detailed tabulated statement of quantities, the reader can form a very accurate idea of its general design.

In comparing the costs of any two concrete bridges, the first step should be to ascertain the cost per lineal foot measured between abutments. If there are several arches in series, the same holds true. If the bridges are single or double track railway structures a direct comparison of costs is then possible, but if they are highway bridges, it is necessary to ascertain the cost per square foot of floor area, for highway bridges differ so greatly in width. This floor area should not be estimated for the total length of the bridge over all, but only for the length between the abutments of the extreme spans. The retaining walls of highway bridges are frequently mere extensions of the spandrel walls, and it is deceptive to include all the area between these retaining walls as floor area, although it is frequently done. The fraction of a yard of concrete per sq. ft. should be stated. Where a large main arch is approached on each side by a number of small arches or by a concrete trestle, it is clear that the major part of the cost of the bridge may often be charged to this main arch. Hence it is not good practice to lump both the main arch and the approaches together in estimating the cost per lin. ft. or per sq. ft. of floor. Yet this is almost invariably done, as will be seen from the following records. One cost per lin. ft. or per sq. ft. should be estimated for the main span or spans, and a separate unit cost for the approach spans.

The live loads should be stated as a rule, although if the date of construction is given, together with the type of bridge, an engineer can readily ascertain what was the prevailing practice as to loading at that time. Since nearly all the bridges recorded in this article were built during the last decade, it seems unnecessary to state the loading.

The reader should note the fact that many of the concrete railway bridges have replaced steel bridges and that in nearly every case the steel bridge was approximately 20 years old when replaced. These steel bridges had in all cases become too light for the heavy locomotives and cars. So far as the past is concerned, this indicates a depreciation in steel railway bridges of about 5% per annum in America—a fact which is itself worthy of sober thought on the part of the bridge designer. We may also add in this connection that the average life of an American locomotive is not far from this same 20 years.

We shall first give the records of materials or cost, or both, of 20 highway bridges, as completely as was possible to secure them. It will be noted that for the usual spans of arches and heights of piers, reinforced concrete highway bridges have cost about $4 per sq. ft. of floor area.

Cost of 25-ft. Arch for Highway.—A reinforced concrete highway bridge was built in 1902 in Wabash county, Ind. It is an arch with a span of 25 ft., a crown thickness of 8 ins. and a roadway 16 ft. wide. The abutments are tied together by steel rods buried in a concrete pavement below the bed of the stream, according to the Luten method. The contract price was only $573, which is equivalent to $23 per lin. ft., or $1.44 per sq. ft. of floor. This price bears testimony to the economy of the design.

Cost of 45-ft. Arch for Highway.—A reinforced concrete highway bridge was built in 1902 over the River Des Peres, Forest Park, St. Louis, Mo. It is a single arch span of 45 ft., with a rise of 12 ft., and a width of 45 ft. out to out. The abutments are 8 ft. high to the spring line. The bridge cost $12,600 (including $2,000 for excavation and riprap), which is equivalent to $280 per lin. ft., or $6.20 per sq. ft. of floor.

Cost of 54-ft. Arches for Highway.—A reinforced concrete highway bridge was built in 1903 across the Kalamazoo River at Plainwell, Mich. The bridge is 414 ft. long between abutments, and has an 18 ft. carriage way and one 5-ft. sidewalk. It consists of 7 arches having a span of 54 ft. and a rise of 8 ft. Piers are only 6 ft. high to the spring line, 6 ft. wide at the spring line and rest on piles. The water was only 4 ft. deep. The arches are 1:2:4 concrete and the piers, etc., 1:3:6. The arches are reinforced with 4-in. channel steel. The materials used were:

	Cu. Yds.
Concrete in foundations	570
Concrete in arches	770
Concrete in walls	150
Concrete total	1,490

Steel, 36,000 lbs.

Earth fill, 1,944 cu. yds.

The contract price was $19,900, which is equivalent to $2.10 per sq. ft. of floor. There is less than 0.16 cu. yd. of concrete per sq. ft. of floor.

The detailed cost of this bridge is given in Gillette and Hill's "Concrete Construction—Methods and Cost."

Cost of 60-ft. Arches for Highway.—A reinforced concrete highway bridge was built in 1906 across the Hudson River at Sandy Hill, N. Y. The bridge is 984 ft. long between abutments and 35 ft. wide. Its deck is 24 ft. above the water surface. The river is shallow and flows over a slate rock bottom. The water is 8 ft. deep only at times of very high water. The bridge consists of 15 arches of 60 ft. span and 8½ ft. rise. The piers are 13 ft. high to the spring line. Each arch span is composed of 7 reinforced concrete arch ribs, and the ribs support a reinforced concrete slab flooring. All concrete was a 1 : 2 : 4 mixture, except the hearting of piers and the footing courses, which were 1 : 3 : 5. About 11,000 bbls. of cement were used. The outside facing of the piers and parapet walls consisted of concrete blocks. The bridge was built by day labor at a cost of $80,000, which is but slightly more

than $80 per lin. ft., or $2.30 per sq. ft. of floor, which is an exceptionally low cost per sq. ft., and indicates excellent design. The bridge was designed and built by Mr. M. O. Kasson of Sandy Hill, N. Y.

Cost of 66-ft. Arches for Highway.—A reinforced concrete highway bridge was built in 1903 at Bridge St., Jacksonville, Fla., over the tracks of several railways, by the Concrete-Steel Engineering Co., under the Melan and Thatcher patents. The total length is 845 ft., consisting of 11 arches, having an average span of about 66 ft. and a rise of 7 ft., with piers about 20 ft. high and 126 piles under each pier. The width of the bridge was 58 ft. between hand rails. The contract price was $149,900, which is equivalent to $177 per lin. ft., or $3 per sq. ft. of floor.

Cost of 80-ft. and 65-ft. Arches for Highway.—A reinforced concrete highway bridge of ingenious design was built in 1904 across Clifty Creek, six miles north of Greensburg, Ind., by the National Bridge Co., of Indianapolis, Daniel Luten, president. The bridge is an arch of 80 ft. span and 12 ft. rise, and has a 16 ft. roadway. The abutments are connected by steel tie rods embedded in concrete, which forms a pavement over which the creek flows. The use of these tie rods greatly reduces the mass of concrete required in the abutments. The mean depth of water was 3 ft. There were 4,500 lbs. of steel used in the ties connecting the abutments, and 4,800 lbs. in the arch and spandrel walls. The concrete amounted to only 265 cu. yds. and the contract price for this bridge complete was only $2,695, which, so far as we know, breaks all records for low cost of a single concrete arch bridge of 80 ft. span. The cost was therefore only $34 per lin. ft., or $2.10 per sq. ft. of floor, or $10 per cu. yd. There is only 0.26 cu. yd. per sq. ft. of floor. This design of Luten arch is illustrated on page 785 of Reid's "Concrete and Reinforced Concrete Construction."

Another highway bridge of the same type is the East Washington St. bridge at Indianapolis. It has a span of 65 ft., a rise of 10 ft. and a roadway 57 ft. wide. It contains 1,100 cu. yds. concrete and the contract price was $10,885, which is equivalent to $167 per lin. ft., or less than $3 per sq. ft. of floor, or $10 per cu. yd. There is 0.3 cu. yd. of concrete per sq. ft. of floor.

Cost of 75 to 100-ft. Arches for Highway.—A reinforced concrete highway bridge was built in 1905 across the Wabash River at Peru, Ind. Its length is 700 ft., and the roadway is 30 ft. wide. The height of roadway is 30 ft. above low water. The bridge consists of 7 arch spans; one 100, two 95, two 85 and two 75 ft. The rise of the arches is 13 to 15 ft. The piers average 30 ft. high and rest on solid rock 6 to 16 ft. below low water. The bridge contains 5,000 cu. yds. of concrete, which required 6,000 bbls. of cement. The concrete was reinforced according to the Luten system. The contract price was $36,900, which is equivalent to only $53 per lin. ft., or $1.80 per sq. ft. of floor, or $7.20 per cu. yd. There is 0.24 cu. yd. of concrete per sq. ft.

This is a remarkably low cost and is indicative of good design. 'his contract price was lower than competitive bids for a steel

bridge of the same length having wooden flooring. This bridge was designed by the National Bridge Co. of Indianapolis, Ind., Daniel Luten, president.

Cost of 80-ft. Arch for Highway.—A concrete highway bridge was built in 1901 across San Leandro Creek, near Oakland, Cal. It is an arch (not reinforced) having a span of 81 ft., a rise of 26 ft., a crown thickness of 3 ft. and supports a macadam carriage way 41 ft. wide with 8 ft. sidewalks on each side, giving a roadway 57 ft. wide. The abutments have a thickness of 30 ft. and extend only 5 ft. below the spring line, and rest on clay. There were 90,000 ft. B. M. used in the centers and forms, or 24 ft. B. M. per cu. yd. of concrete. The spandrel walls have a length of 192 ft. each. There are 3,384 cu. yds. of concrete in the bridge, and the contract price for its construction was $25,840, which is equivalent to $319 per lin. ft. of span, or $5.60 per sq. ft. of floor. There are $.74 cu. yds. of concrete per sq. ft. of floor. The concrete was a 1 : 2 : 7 mixture, and it will be seen that the contract price for the bridge was equivalent to about $7.70 per cu. yd. of concrete.

Cost of 85-ft. Arch for Highway.—A reinforced concrete highway bridge was built in 1903 at Seeley St., over Prospect Ave., Brooklyn. The arch has a span of 85 ft. and a rise of 8½ ft. The carriage way is 32 ft. wide and the sidewalks are each 12½ ft. wide, making a total width of roadway of 57 ft. The total length of each parapet wall is 144 ft. The abutments are 15 ft. high to the spring line. The bridge contains 1,300 cu. yds. of concrete, and 91,400 lbs. of corrugated reinforcing bars. The contract price was $21,800, which is equivalent to $256 per lin. ft., or $4.53 per sq. ft. of floor, or nearly $17 per cu. yd. There is 0.27 cu. yd. of concrete per sq. ft. of floor.

Cost of 69 to 88-ft. Arches for Highway.—A reinforced concrete highway bridge was built in 1903 across the Great Miami River on Main St., Dayton, Ohio. Its length is 588 ft. between abutments, and it has a carriageway 40 ft. wide and two 7-ft. sidewalks, making a total width of 54 ft. It consists of 7 arches having spans of 69 to 88 ft., reinforced according to the Melan system. The rise of the arches is 1-10 to 1-13 of the span. The piers are 31 ft. high to the spring line, and the base of piers is about 15 ft. below low water. The contract price was $123,170, which is equivalent to $210 per lin, ft., or slightly less than $4 per sq. ft. of floor.

Cost of 80 to 110-ft. Arches for Highway.—A reinforced concrete highway bridge was built in 1904 across the Great Miami River at Third St., Dayton, Ohio. The bridge consists of 7 arches and has a total length of 710 ft. between abutments, and its width is 62 ft. between balustrades. It is of the Melan type, designed by the Concrete-Steel Engineering Co., which received a royalty of $12,000 paid out of the contract price. The arch spans ranged from 80 ft. to 110 ft., with a ratio of span to rise averaging about 7½ to 1. The piers were 22 ft. high. The contract price was $179,600, which is equivalent to $253 per lin. ft., or about $4 per sq. ft. of floor.

Cost of 100-ft. Arch for Highway.—A reinforced concrete highway bridge was built in 1907, in Rock Creek Park, Washington, D. C.,

on Ross Drive across Rock Creek. The length is 168 ft. and its width is 16 ft. It consists of a main span of 100 ft. having a 15-ft. rise, with concrete trestle approaches 30 ft. long on each side. The three hinged arch span consists of three ribs carrying, at intervals of 10 ft., light spandrel columns supporting the reinforced concrete beams and floor slabs. A steel handrail is provided on each side. An existing timber trestle was utilized for centering. The bridge was designed for a live load of 100 lbs. per sq. ft., with a concentrated load of only 6 tons on a four-wheel wagon. The bridge was built by day labor and cost $8,000, or $50 per lin. ft., or $3.20 per sq. ft. of floor, including approaches.

Materials in 50-ft. and 100-ft. Arches for Highway.—A concrete highway bridge was built in 1903 over a mill pond on the Anthony Kill, near Mechanicsville, N. Y. Its length is 265 ft. between abutments, and its width is 17 ft. over all. It consists of two 100-ft. arches and one 50-ft. arch not reinforced. The rise of the 100-ft. arches is about 20 ft. The piers have a height of about 15 ft. Piles were driven to support the centers. There were 140,000 ft. B. M. in the centers and forms, which lumber was used but once. About 2,500 cu. yds. of concrete were required, or 0.56 cu. yd. per sq. ft. of floor. Therefore it took 56 ft. B. M. per cu. yd. of concrete. The centers consisted of bents supporting lagging laid parallel with the center line of the roadway.

Cost of 125-ft. Arch for Highway.—A concrete highway bridge was built in 1906 at 16th St., Washington, D. C., known as the Piney Creek bridge. Its length is 272 ft. and its width is 25 ft. It consists of a parabolic arch having a span of 25 ft. and a rise of 39 ft., resting on abutments about 12 ft. high, and a concrete viaduct approach on each side of the arch. The arch is not reinforced and is 5 ft. thick at the crown. It carries a solid spandrel wall on each side and reinforced concrete posts between the walls, which support the reinforced concrete slab roadway. The viaduct approaches are merely extensions of this spandrel construction, and have an average height of about 65 ft.

The design of this bridge is illustrated and described in Reid's "Concrete and Reinforced Concrete Construction." The cost of the bridge was $52,231, of which $3,000 was for engineering and $1,500 for inspection. This is equivalent to a cost of $200 per lin. ft., or $8 per sq. ft. of floor area.

Cost of 135-ft. Arch for Highway.—A reinforced concrete highway bridge was built in 1907 across Cherry Creek, at Bannock St., Denver, Colo. The bridge is a one-arch span of 135 ft., consisting of 8 parabolic three hinged arch ribs. This design was adopted because the bridge crosses the creek on a skew of 36°. The rise of the arch is 13 ft., and the arch is 24 ins. thick at the crown. The arch supports a reinforced concrete slab floorway resting on reinforced concrete spandrel posts. The carriage way is 36 ft. wide, flanked by an 8-ft. sidewalk on each side, giving a total width of 52 ft. of roadway. The bridge contains 1,146 cu. yds. of 1 : 2 : 5 concrete, 166,000 lbs. of steel reinforcement and 33,000 lbs. of steel

castings. There is less than 0.28 cu. yd. per sq. ft. of floor. The contract price was $28,325, or $210 per lin. ft., or $4 per sq. ft. of floor space, or $24.60 per cu. yd. of concrete. This low cost per square foot for so long a span indicates excellent design on the part of Mr. Charles W. Comstock, M. Am. Soc. C. E. Contrast this design and cost with the design and cost of the Piney Creek bridge above given.

Cost of 150-ft. Arches for Highway.—A concrete highway bridge was finished in 1907 over Rock Creek, Washington, D. C., and is known as the Connecticut Ave. bridge. It has a total length of 1,068 ft. between abutments. The abutments are U shape, and are filled with earth, giving a total length of 1,341 ft. of bridge including abutments. The bridge consists of five concrete arches (not reinforced), each of 150-ft. span and 75-ft. rise, and two 82-ft. arches of 41-ft. rise. The 150-ft. arches support spandrel arches that carry the roadway. The roadway is about 150 ft. above the base of foundation of the center pier. The bridge is 52 ft. wide. It contains 80,000 cu. yds. of concrete, or 1.62 cu. yds. per sq. ft. of floor. The cost was $850,000, or $639 per lin. ft. of total length, which is equivalent to $12.30 per sq. ft. of floor. Full detailed costs of the materials and labor required to build this bridge are given in Gillette and Hill's "Concrete Construction—Methods and Cost."

Cost of 233-ft. and 53-ft. Arches for Highway.—A concrete highway bridge was built in 1906 across the Wissahickon Creek, Philadelphia, and is known as the Walnut Lane bridge. The bridge is 585 ft. long and 60 ft. wide, having a 40-ft. roadway and two 10-ft. sidewalks. It consists of a main arch of 233 ft. span, approached on one side by three 53-ft. arches and on the other side by two 53-ft. arches. The main arch has a rise of 70 ft. and supports 8 spandrel arches. The abutments for this main arch have a height of 15 ft. and rest on rock. The concrete is not reinforced. The main arch consists of twin arch rings, side by side. The contract price for this bridge was $253,551, which is equivalent to $434 per lin. ft., or $7.25 per sq. ft.

Estimated Cost of 703-ft. Arch for Highway.—Plans for a reinforced concrete highway bridge of unprecedented size have been prepared for the city of New York, and the estimated cost and amount of materials are worthy of record here. The bridge is to be known as the Hudson Memorial Bridge, and is to cross Spuyten Duyvil Creek. The bridge is to be 2,840 ft. long and 80 ft. wide. The main arch is 703-ft. span and 170-ft. rise, 70 ft. wide, 15 ft. thick at the crown and 28 ft. thick at the spring, and supports 10 spandrel arches. The approaches consist of 3 arches of 100 ft. span on one side and 4 on the other side. The bridge is to carry two decks, one for highway traffic and the other for rapid transit railway traffic. The steel in the arch ring is to be used in compression and is, strictly speaking, not a reinforcement. It averages about 1¾% of the volume of the arch ring. There are to be 17,000,000 lbs. of steel in the 47,000 cu. yds. of concrete in the arch ring.

The total amount of concrete is to be 75,000 cu. yds. in the main arch, including the spandrels, foundations, etc., which will contain 24,000,000 lbs. of steel. The estimated cost of the arch and approaches (2,840 ft. long) is $3,800,000, which is equivalent to nearly $1,340 per lin. ft., as nearly $17 per sq. ft.

Cost of a Stone Arch Highway Bridge.—A stone highway bridge was built in 1904 across the Connecticut River at Hartford. It is 1,185 ft. long and 80 ft. wide between parapets. It consists of 8 stone arches, having spans of 68 to 119 ft., and a 100-ft. Scherzer rolling lift bridge. The foundations for the piers were put down with pneumatic caissons. The toe of each caisson averaged about 30 ft. below low water level and 50 ft. below the spring of the arch. The piers and parapets are faced with granite, and the backing is concrete. There were 23,300 cu. yds. of concrete in caisson piers, 32,000 cu. yds. concrete backing, 9,300 cu. yds. granite ashlar, 10,000 cu. yds. granite voussoirs, 9,500 cu. yds. arch ring concrete and 300 cu. yds. granite parapet and posts, or a total of 84,400 cu. yds. masonry. There were 20,000 cu. yds. excavation for abutments and 37,800 cu. yds. dredging and excavation for piers. The contract price for the masonry and foundations was $1,369,520 and the total was $1,600,000, or $1,330 per lin. ft., or $17 per sq. ft. of floor.

Cost of Longest Stone Arch Bridge.—The longest stone arch bridge span in the world was begun in 1903 at Plauen, Saxony. It is a highway bridge with a roadway 36 ft. wide flanked by two sidewalks 10 ft. wide each, making a total width of 56 ft. The arch has a span of 295 ft. and a rise of 59 ft., and a crown thickness of 4.9 ft. It springs directly from ledge rock. The bridge has a total length of 492 ft. and is built throughout of stone masonry. There are about 15,000 cu. yds. of masonry in the bridge, and 848,000 ft. B. M. of timber were required for the centers and falsework. The centers rested on concrete footings. The cost of the bridge was only $120,000, due to the low cost of labor in Saxony. This is equivalent to $8 per cu. yd. of masonry. Hence the bridge cost $244 per lin. ft., or $4.35 per sq. ft. of roadway.

Estimated Cost of 50, 75 and 100-ft. Electric Railway Arches.—In estimating the cost of double track reinforced concrete bridges for interurban electric lines, Mr. George P. Carver gives the following quantities for 50, 75 and 100-ft. single span arches having a width of 28 ft. These arch spans were all designed to cross streets (not rivers) and had hollow reinforced concrete abutments.

Span. Ft.	Concrete. Cu. Yds.	Steel. Lbs.	Cost.
50	370	27,700	$4,730
75	740	38,800	8,830
100	1,008	55,650	12,150

It will be noted that the estimated cost is $12 to $13 per cu. yd. of concrete, not including the cost of excavation. Prices assumed in making the estimates were as follows:

Steel, 2½ cts. per lb.
Placing steel, 1 ct. per lb.
Cement, $2 per bbl.
Stone, $2 per cu. yd.
Sand, $1 per cu. yd.
Forms, $1 per cu. yd.
Mixing and placing, $1.50 per cu. yd.
Add for incidentals, 15%.
Add for profit, 10%.

Materials in Concrete Railway "Trestle."—A double track reinforced concrete bridge was built in 1900 across Ames Creek for the Illinois Central Ry. It is 72 ft. long between abutments, and is 36 ft. wide out to out. It consists of 4 spans of 15 ft. each, which are such flat arch spans that they are really girders. Fourteen steel I beams (9 in.) are embedded in these spans for reinforcement. The concrete is 18 ins. thick at the crown. The piers are 3 ft. thick at the top and 10 ft. high, resting on piles. The bridge contains 725 cu. yds. of concrete, or 10 cu. yds. per lin. ft.

Materials in Concrete Railway "Trestle."—A double track concrete trestle was built in 1906 across Cave Hollow Creek for the C., B. & Q. Ry. The total length is 80 ft. between abutments. It consists of five spans of 14 ft. each resting on piers 2 ft. wide on top, 30 ft. long and 16 ft. high. The footing of each pier is 5 ft. wide and rests on 26 piles 16 ft. long. The abutments are 12 ft. high. The superstructure is composed of reinforced concrete slabs 16 ft. long, 28 ft wide and 2 ft. 4 ins. thick, with a parapet 1 ft. high on each side. There are 34,000 lbs. of Johnson corrugated bars and 520 cu. yds. of concrete in this trestle, or 6.5 cu. yds. per lin. ft. A 1 : 2 : 4 concrete was used in the superstructure and a 1 : 3 : 6 in the piers and abutments.

Cost of Concrete Railway "Trestle."—A single track concrete trestle was built in 1905 for the Illinois Central Ry. at New Athens, Ill. Its length is 82 ft. between abutments and its width is 15 ft. over all or 12 ft. between parapet walls. It consists of 5 arch reinforced spans of 14 ft. each resting on solid piers 3 ft. thick and 19 ft. high. The arches are eliptical, having a rise of 4 ft. and a crown thickness of 16 ins. The footing of the piers is spread at the base to 8 x 19 ft., giving a load on the earth of 1¼ tons per sq. ft. The extrados of the arches is very flat and is at subgrade at the crown, so that the parapet wall, which is 18 ins. thick, has a height of only 18 ins. above the crown. A 1 : 2 : 5 concrete was used. The cost was about $7,500, which is equivalent to $91 per lin. ft., including a large amount of excavation for piers and abutments.

Cost of 38-ft. Arch for Railway.—A three-track reinforced concrete bridge was built in 1905 across Trim Creek, near Chicago, for the Chicago & Eastern Illinois Ry. The bridge is a reinforced concrete arch span of 38 ft. having a rise of 7 ft. and a width of 48 ft. The abutments are 15 ft. high to the spring. The arch is 26 ins. thick at the crown. The bridge contains 1,578 cu. yds. of concrete and 36,000 lbs. of Johnson corrugated bars. A similar bridge built for the same road cost $7.60 per cu. yd., including the

reinforcing bars, at which rate this bridge would cost about $12,000 or $315 per lin. ft., or $6.55 per sq. ft. There is 0.86 cu. yd. per sq. ft.

Cost of 64-ft. Arches for Railway.—A double track stone and concrete bridge was built in 1903 across Rock River, at Watertown, Wis., for the C., M. & St. P. Ry., replacing a single track iron bridge built 19 years previously. It is 280 ft. long between abutments and 30 ft. wide over all. It consists of 4 stone arch spans of 64 ft each, with a rise of 16½ ft. and a crown thickness of 3 ft. The piers are 8 ft. wide at the spring line and 15 ft. high to the spring line, and rest on piles. The parapet walls are each 360 ft. long. The bridge contains 4,000 cu. yds. of stone and concrete masonry, and its cost was $40,700, including removal of the old bridge, building a temporary bridge, filling and new track. This is equivalent to $145 per lin. ft., or $4.80 per sq. ft., or $10.20 per cu. yd. There is 0.48 cu. yd. per sq. ft.

Cost of 68-ft. and 82-ft. Arches for Railway.—A double track reinforced concrete railway bridge was built in 1906 across the Sangamon River, near Decatur, Ill., for the Wabash Ry. Its length is 386 ft. between abutments and its width is 25 ft. between parapet walls. The bridge consists of 4 skew arches (45° skew), two of which have a clear span of 58 ft., measured perpendicular to the piers, or a span of 82 ft. measured along the center line of the railway. The other two arches each have a clear span of 48 ft. measured perpendicular to the piers, or 68 ft. along the center line. The rise of the arches is 30 ft. and the piers have a height of 35 ft. The three piers are in water about 5 ft. deep. At each end of the bridge is an abutment with side retaining walls 125 ft. long. This bridge was reinforced with corrugated bars. It replaced a steel bridge built 21 years previously. The following quantities were involved in the construction:

Earth excavation, cu. yds.	8,320
Piling, lin. ft.	36,775
Foundation slabs for piers, concrete, cu. yds.	1,300
Piers proper, with skewbacks, concrete, cu. yds.	2,270
Arch rings, concrete, cu. yds.	2,370
Spandrel walls of arches, concrete, cu. yds.	2,180
Foundations for abutments, concrete, cu. yds.	1,580
Abutments above foundations, including slabs and intermediate walls, together with spandrel walls, concrete, cu. yds.	5,930
Retaining walls, concrete, cu. yds.	540
Reinforcing bars, lbs.	430,000

The cost was $124,000, which is equivalent to $321 per lin. ft., or $12.80 per sq. ft. of roadway. The total amount of concrete is 16,170 cu. yds., so that the cost of the bridge was equivalent to $7.65 per cu. yd. There are 1.68 cu. yds. per sq. ft.

Materials in 74-ft. Arch for Railway.—A four-track concrete bridge, 160 ft. long, was built in 1904 across the Ashtabula River, Ohio, for the Lake Shore Ry. It comprised two 74-ft. concrete arches having a rise of 37 ft., resting on piers and abutments only 6 ft. high. The arches were 7 ft. thick at the crown and 21 ft. at the spring, and were not reinforced. An earth fill 30 ft. deep over

the crown was placed upon the arches, making it necessary to have the barrels of the arches 145 ft. long. There were 17,500 cu. yds. of concrete and 50,000 cu. yds. of earth fill. This bridge is a good example of poor design, for, at $8 per cu. yd. for concrete and 15 cts. per cu. yd. for fill, its cost would be $147,500, or more than $900 per lin. ft., or about $18 per sq. ft. of roadway. A narrow bridge with spandrel piers supporting the roadway could have been built at far less cost. It will be noted that there were about 2.2 cu. yds. of cnncrete in this bridge per sq. ft. of roadway.

Materials in 75-ft. Arch for Railway.—A reinforced concrete railway bridge was built in 1903 over Big Rock Creek, 51 miles west of Chicago, on the line of the C., B. & Q., replacing a steel bridge built 22 years previously. The span is 75 ft. The bench walls are 12 ft. high, and the rise of the arch is 28 ft. It is a three center arch 3 ft. thick at the crown and the barrel length is 44 ft. There is no appreciable fill over the crown. The arch is designed for a loading of 1,000 lbs. per sq. ft. The wing walls are each 55 ft. long, and 10½ ft. thick at the bottom. The abutments of the arch are 25 ft. wide at the base. Abutments and wing walls rest on piles. Corrugated steel bars are used for reinforcement. There are 6,588 ft. of ¾-in. bars and 24,046 ft. of ⅞-in. bars in the bridge. The arch ring is 1 : 2 : 4 concrete and contains 770 cu. yds. The rest of the concrete is 1 : 3 : 6. The total concrete in the structure is 3,350 cu. yds., or nearly 45 cu. yds. per lin. ft., or 1 cu. yd. per sq. ft.

Materials in 80-ft. and 100-ft. Arches for Railway.—A double track concrete bridge was built in 1906 across the Vermillion River, for the Cleveland, Cincinnati, Chicago & St. Louis Ry. It consists of two 80-ft. arches and one 100-ft. arch between them. The piers of the 100-ft. arch are 30 ft. high to the spring line, and the arch has a rise of 40 ft. These main arches support a series of small spandrel arches having spans of 8 ft., resting on piers 2 ft. thick. The crown thickness of the 100-ft. arch is 4 ft. The base of rail is 20 ft. above the crown and 90 ft. above the foundations of the center piers. The bridge has a total length of 290 ft. between abutments, a width of 29 ft. between parapets, and contains 12,000 cu. yds. concrete, or nearly 41 cu. yds. per lin. ft., or 1.41 cu. yds. per sq. ft. The bridge is designed as a plain concrete bridge, although steel reinforcement is used as a precautionary measure. There were 260,000 lbs. of Johnson corrugated bars used. The bridge required 500,000 ft. B. M. for centers and forms, which is equivalent to 42 ft. B. M. per cu. yd.

Materials in 100-ft. Arches for Railway.—A single track concrete bridge was built in 1906 across the Cumberland River for the Kentucky & Tennessee Ry. It is 500 ft. long between abutments, consisting of 5 spans of 100 ft. c. to c. of piers, and the width is 16 ft. between parapet walls. The bridge is on a 30° skew. The arches have a rise of 18 ft. and a crown thickness of 3 ft. 7 ins. The piers are 40 ft. high. There are 6,470 cu. yds. of concrete and 240,000 lbs. of twisted steel reinforcement in this bridge. This is equivalent to nearly 13 cu. yds. per lin. ft. of bridge, or about 0.8 cu. yd. per sq. ft. of roadway.

Cost of 140-ft. Arches for Railway.—A double track concrete railway bridge was built in 1902 across the Big Muddy River for the Illinois Central Ry., to take the place of a single track steel bridge built 13 years previously, which was getting too light for the traffic. The bridge is 463 ft. long between abutments and 32 ft. wide, or 26 ft. between parapet walls. It consists of three elliptical arches (not reinforced), each having a span of 140 ft., a rise of 30 ft. and a crown thickness of 7 ft. These main arches supported spandrel arches of 13 ft. span reinforced with steel skeletons made principally of rails. The piers are about 22 ft. high to the spring line and are built around and over the old single track bridge piers.

The total cost was $125,000, which is equivalent to $270 per lin. ft., or $10 per sq. ft. of roadway. There were 12,000 cu. yds. of concrete, or 26 cu. yds. per lin. ft., or 1 cu. yd. per sq. ft. of roadway; 5,000 cu. yds. of excavation, which cost 76 cts. per cu. yd.; 400,000 ft. B. M. in cofferdams, centers and forms, and 300,000 lbs. steel reinforcement. The labor cost of handling, punching and erecting the steel was 0.61 ct. per lb.

Materials in 140-ft. Stone Arch for Railway.—A double track stone bridge was built in 1899 across the Connecticut River, at Bellows Falls, Vt., for the Fitchburg railroad. It consists of two stone arch spans of 140 ft. each, having a rise of 20 ft. The width over all is 27 ft. The arch sheeting is 4 ft. thick. The bridge is peculiar in that it has no masonry abutments or pier, the arches springing directly from ledge rock on each bank and from a rock island in the center of the stream. This natural pier in the middle of the river is 32 ft. thick along the spring line, thus giving a total length of bridge of 312 ft. between the natural abutments. There were 232,000 ft. B. M. required for the centers, or 55 ft. B. M. per cu. yd. of masonry in the bridge. The masonry was as follows:

	Cu. Yds.
Ring stones and skewbacks	1,262
Coping	286
Rubble	2,467
Concrete in foundations	180
Total	4,195

This is equivalent to 13½ cu. yds. per lin. ft.

Price of a Concrete Arch Highway Bridge.—Mr. William B. Barber gives the following data: This highway bridge crosses San Leandro Creek, Cal. It has a macadam roadway 41 ft. wide, and two 8-ft. cement walks. The span is 81¼ ft., the rise is 26 ft., and the thickness is 3 ft. The footings have at the crown a width of 30 ft. on each side and extend 5 ft. below the bed of the creek, resting upon a bed of clay without any pile supports. There were 90,000 ft. B. M. of lumber in the centers. The concrete was a 1:2:7 of broken stone. The bridge contains 3,389 cu. yds. and was built at a contract price of $25,840 by the E. B. & A. L. Stone Co., of Oakland, Cal.

Materials in a Concrete Highway Bridge.—A concrete arch highway bridge was built across the River Eyach, near Inman, Germany, in 1896. It is a three-hinge arch, the hinges being of granite with intermediate sheets of 3/16 in. lead. The span is 98 ft.; the rise is 9.8 ft.; the thickness at the crown is 1.48 ft.; at the haunches, 2.62 ft.; at the spring joint, 1.64 ft. The carriageway is only 8.2 ft. wide, and the two sidewalks are each 2.46 ft.; total, 13.12 ft. The arch spreads in width to 11.48 ft. at the spring lines. The roadway rests on the arch at the center, and is supported by four spandrel arches resting on three piers at each end. Each abutment rests on 41 batter piles, 13 ft. long. The bridge was designed to carry 74 lbs. per sq. ft. and a 16½ ton steam roller, with compressure stress not exceeding 480 lbs. per sq. in., and tensile stress not exceeding 57 lbs. There are 408 cu. yds. of concrete in the bridge, including foundations, built for $3.20 per cu. yd. for foundation and $8.24 for arch. Contract price was $2,930, including excavation and piles.

Dimensions and Cost of Forty-five Concrete Arch Bridges.—In *Engineering-Contracting*, Mar. 17, 1909, the following table of costs, by Mr. E. P. Goodrich, is printed.

Table XX gives some of the dimensions and costs of a number of arches. In the case of single arch spans, the cost per square foot is computed from face to face of abutments and out to out of railings.

Cost of Concrete Bridges.—In a table covering eighteen concrete arch bridges recently built in Philadelphia the contract price spread upon the span area—the clear span by the width—varies from $3.11 to $9.74 per sq. ft. and it varies from $1.73 to $7.39 per sq. ft. of area occupied by the ground plan to ends of wings, the latter extremes being not on the same bridges as the other two. The average of the lot was $6.25 per sq. ft. of span area and $3.50 per sq. ft. over all, most of them being single span bridges with long wings, and all being highway bridges designed to carry loads of 40 tons on two axles 20 ft. apart. All have ornamental concrete balustrades and washed granolithic surfaces and paved decks, with electrical conduits and manholes, and water pipe and sewer well-holes and some have pretty deep foundations. If the whole contract price be set against the yardage of the concrete in the structure the unit costs vary from $8.50 to $11.25 per cu. yd., averaging $9.75. Mr. Henry E. Quimby, Engineer of Bridges, Philadelphia, Pa., is authority for these figures.

Concrete Arch Bridge, S. P., L. A. & S. L. R. R.—Mr. A. C. Ostrom gives the following facts about an eight-arch bridge crossing the Santa Ana River on the San Pedro, Los Angeles & Salt Lake R. R. The bridge is 984 ft. long, 17 ft. wide, 55 ft. high (averaged), and contains 14,000 cu. yds. of concrete without any steel reinforcement. Each arch has a radius of 43½ ft., a rise of 37 ft., and a thickness of 42 ins. at the crown. The arch ring projects 6 ins. beyond the face of the spandrel walls. The piers have a footing 16 × 28 ft. resting on granite, and narrow by steps

TABLE XX.—DIMENSIONS AND COSTS OF CONCRETE ARCH BRIDGES.

Place.	Over.	Total Length Bridge.	Arch Spans.	Width.	Rise of Arch.	Total Cost.	Cost per sq. ft.	Date Erected.
Pine Road, Philadelphia	Pennypack Creek	....	2a 25'4½"	34'3½"	6'6"	$ 8,662	$4.94	1893
Neuhansel, Hungary	Neutra	....	6a 55'9½"	19'8"	3'8½"	13,700	2.00	1893
Munderkingen, Wurtemburg	Daubne	....	164'0"	26'3"	16'5"	21,420	4.50	1894
Richmond Ave., Syracuse	Harbor Brook	....	12'0"	49'0"	2'6"	2,000	3.40	1894
Eden Park, Cincinnati	Park Ave	....	70'0"	32'0"	10'0"	7,130	3.15	1895
Stockbridge	Housatonic	....	100'0"	7'6"	10'0"	1,475	2.00	1895
Belleville, Ill	Richmond Creek	....	40'0"	52'0"	7'0"	10,500	3.90	1895
Topeka	Kansas River	693'0"	5a 125'0" 2a 110'0" 2a 97'6"	40'0"	....	125,000	4.50	1896
Inzigkofen	Danube	....	141'0"	12'0"	14'4"	6,650	3.70	1896
Immau	Eyach	....	98'5"	13'1"	9'10"	4,285	3.30	1898
Green and Goat Islands	Niagara	371'0"	2a 103'6" 1a 110'0" 2a 50'6" 1a 55'0"	40'0"	....	102,070	4.50	1900
Indianapolis	Fall Creek	198'0"	6a 74'0"	65'0"	9'6"	105,340	3.70	1900
Juana Diaz, Porto Rico	Jacaguas River	404'0"	1a 120'0" 2a 100'0"	18'0"	12'0" 11'3"	59,438	3.15	1900
Juana Diaz, Porto Rico	Guayo River	270'0"	3a 70'0"	....	7'6" 7'0"	25,683	5.25	1900
Worthington	Piney Branch	....	24'0"	26'0"	5'0"	8,170	5.10	1900
....	Quarry Road	....	80'0"	28'6"	14'0"	21,500	9.40	1900
Chatellerault, France	Vienne	443'0"	164'0"	26'3"	15'0"	35,000	3.00	1901
Washington	Rock Creek	....	80'0"	27'0"	15'0"	17,500	8.10	1901
Wabash Co., Ind	....	....	25'0"	16'0"	....	573	1.45	1902
Forest Park, St. Louis	River des Peres	....	45'0"	45'0"	....	10,600	5.20	1902
Liabach, Austria	Liabach	....	109'4"	50'0"	14'0"	80,000	5.60	1901
I. C. R. R.	Big Muddy River	483'0"	3a 140'0"	34'2"	30'0"	125,000	7.60	1901-3
Plainwell, Michigan	Kalamazoo River	440'0"	7a 54'0"	25'0"	8'0"	19,900	1.80	1903
Saley St., Brooklyn	Prospect Ave	125'0"	85'0"	60'0"	....	21,800	4.30	19—
Munich	Grunwald	720'0"	2a 230'0"	30'0"	42'0"	65,000	3.10	1904
Connecticut Ave., Washington	....	1,341'0"	2a 82'0" 5a 150'0"	52'0"	41'0" 78'0"	850,000	12.20	1905

Place.	Over.	Total Length Bridge.	Arch Spans.	Width.	Rise of Arch.	Total Cost.	Cost per sq. ft.	Date Erected.
16th St., Washington	Piney Branch	272'0"	125'0"	25'0"	30'0"	42,731	6.25	1905
Dayton	Great Miami	588'0"	60'0"-88'0"	56'0"	....	123,170	3.70	1904
Park Ave., Newark	Branch Brook Park	243'7"	132'0"	74'0"	10'2"	84,000	4.70	1905
Connington Viaduct	....	600'0"	10a 50'0"	16'0"	16'0"	52,200	5.43	1903
Greensburg, Ind	Clifty Creek	....	80'0"	16'0"	12'0"	2,695	2.10	......
Wayne St., Peru	Wabash River	500'0"	6a 75' to 100'	30'0"	15'0"	36,900	2.46	......
Wabash, Ind	Charley Creek	....	2a 75'0"	30'0"	18'0"	7,000	1.56	......
Pollaskey	....	800'0"	10a 75'0"	18'0"	11'0"	48,000	3.33	......
Meridian Street	....	250'0"	3a 74'0"	60'0"	9'0"	51,060	2.26	......
E. Washington St., Indianapolis	....	....	65'0"	57'0"	10'0"	10,885	2.94	......
Muncie, Ind	....	....	38'0"	16'0"	7'6"	640	1.22	......
Bangor, Me	....	90'0"	46'7½" 38'2"	40'0"	8'7" 7'6"	6,500	1.80	......
Mieres, Spain	....	333'0"	3a 34'4" 2a 114'4"	23'app	....	"30,300	3.90	......
Skodsbury, Denmark	....	....	71'6"	10'0"	....	2,000	2.80	......
Sandy Hill	....	1,025'0"	15a 60'0"	35'8"	....	72,000	2.00	......
Walnut Lane, Philadelphia	....	585'0"	233'0"	60'0"	....	262,000	7.50	......
Emperor Bridge, Sarajeno	....	....	115'10"	40'0"	12'0"	16,500	12.00	......
Maryborough, Queensland	....	613'0"	a 80'0"	22'8"	4'0"	75,000	5.40	......
Lansing, Michigan	Grand River	....	120'0"	52'10"	23'0"	31,000	4.90	......

to 9 × 21. They are penetrated vertically by two wells 2½ × 5 ft., thus saving concrete and providing drainage by weep holes below and horizontal tunnels at the top of the arch haunch. There are two sets of spandrel walls connected by cross walls, covered by a 10-in. concrete floor which sustains the 3½ ft. of ballast. Cement and gravel in the ratio 1 to 11 were used for the foundations and spandrel walls. The arch rings were made of 1:2:4½ stone concrete. The gravel was washed by means of a sluice passing through a box where the coarse gravel and clean sand settled. Three Ransome mixers were operated by a 25-hp. engine. The arch centers were supported on four bents of four piles per bent driven to bed rock. These were capped by 12 × 12-in. caps. The thrust from the segments was conveyed by radial 8 × 8-in. struts to horizontal chords which were upheld by wedges placed on 12 × 12-in. stringers that rested upon the caps.

Cost of a Reinforced Concrete Arch Highway Bridge.—Mr. P. A. Courtright gives the following on the cost of mixing and placing concrete in a concrete bridge having 7 arches, each of 54 ft. span and 8 ft. rise, at Plainwell, Mich., in 1903, as follows:

	Total per day.	Total per cu. yd.
13 men, at $1.80	$23.40	$0.78
Engine and mixer	5.00	0.17
1 team	3.00	0.10
1 foreman	3.00	0.10
Total labor for 30 cu. yds.	$34.40	$1.15
0.9 cu. yd. gravel, at $0.50		$0.45
0.65 bbl. cement, at $2.00		1.30
Total, per cu. yd.		$2.90

The concrete yardage was as follows:

5.70 cu. yds. of 1:8 gravel concrete in foundations.
770 cu. yds. of 1:6 gravel concrete in arches.
150 cu. yds. of 1:6 gravel concrete in walls.

One sack of cement was considered to be 1 cu. ft. The bridge had an 18-ft. roadway and a 5-ft. side wall, a total length of 446 ft., and the estimate of its cost at contract prices was:

1,490 cu. yds. concrete, at $7.00	$10,430
1,200 cu. yds. earth fill, at $0.30	360
36,000 lbs. of steel, at $0.05	1,800
2,800 ft. of piles in foundations, at $0.20	560
2,230 sq. ft. of cement walk, at $0.10	223
Total	$13,373
Excavating, pumping, coffer dams, and centers, $791 per arch	5,537
Grand total	$18,910

The method of making the concrete was as follows: The gravel, which had 32% voids, and contained sufficient sand, was shoveled into a 1 cu. yd. wagon at the pit, and hauled to a platform at the intake of a McKelvey continuous mixer. Half the cement required for a batch was spread over the load of gravel before dumping the load through the bottom of the wagon; then the rest of the cement was added after dumping. One man shoveled the material over to another man who shoveled it into the mixer. After the material had passed one-third the length of the mixer, water was turned in. The mixer delivered the concrete into wheelbarrows from which it was dumped to place and spread in 3-in. layers. Two men were employed tamping to 1 man shoveling the concrete. The gravel for the arches and walls was screened through a 2-in. mesh screen placed on the wagon while loading at the pit. Regarding the product of the mixer, Mr. Courtright says: "A more complete blending of materials would be difficult to produce." This statement is noteworthy in view of the common prejudice against continuous mixers.

Centers.—The heels were supported on the benches constructed upon each pier and abutment foundation. Each center was supported to the panel joints by twelve temporary piles. These were driven in advance of the foundation work, sawed off, capped with timbers, and used as a working platform.

The centers themselves were made of Georgia pine plank. Each rib section was built up with three planks, two 2 × 12 inch for outside, and one 10 × 2-inch between. These were securely nailed and bolted together, the panels being joined by bolting on two pieces of 2 × 4-inch oak.

The top chord was made of one plank, cut in sections, and rounded to fit the intrados of the arch. The panel joints were supported by 8 × 12-inch timbers, carried on posts resting on 8 × 12-inch timber caps on piles.

Wedges for lowering the centers were used at all bearing points.

Centers were covered with 2 × 12-inch planed pine lagging and made a very rigid and smooth surface for concrete. The minimum of time allowed for the removal of centers after the completion of an arch was 28 days.

The appearance of the arch rings, showing the same divided as by joints between stones, was produced by nailing half round strips on the form, and gives a good structural effect to the work. The entire structure was built in the forms with the single exception of the fourteen keystones, which, owing to their peculiar design, were cast separate, and set in the form.

Piling.—Each abutment foundation has 31 piles, the piers having 23 each. Piles were oak, elm, beech and hickory, not less than 12 ins., nor more than 16 ins. at the head. They cost, delivered on the ground and sharpened ready for driving, 15 cents per lineal foot. The average number driven per day was 8½.

The character of the soil rendered driving very difficult; a penetration of 2 or 3 ins. when starting a pile was the exception rather than the rule.

Cost of driving—

Engine and driver, per day	$ 5.00
Engineer	2.50
Fireman	1.80
Four driver men, at $1.80	7.20
Total	$16.50

Conditions for construction were very favorable. The water varied in depth from 3 to 5 ft., with a current of from two to three miles per hour. Under the silt and sand which formed the river bed, gravel was found to depth of about 3 ft.; below this, quicksand, filled with stones of varying sizes, was encountered.

For foundations, piles were driven to an approximate depth of 10 ft. below the bed of the stream. Cofferdams were built, the water pumped out, and the excavation carried down until 1 ft. of gravel was left above the quicksand. The piles were sawed off 1½ ft. above the bottom of the excavation, and the concrete carried up to the spring line of the arches.

Cost of Three Reinforced Concrete Arch Bridges, L. S. & M. S. Ry.—Mr. Samuel Rockwell gives the following as to the size and cost of three reinforced concrete railway arch bridges. The bridge arches had a span of 30 ft., a rise of 9 ft., a crown thickness of 33 ins., a thickness at the spring of 6½ ft., and a barrel length of 40, 60 and 160 ft., respectively. The abutments were 8 ft. high and 14 ft. wide at the base. Johnson corrugated steel bars were used, for reinforcement. The concrete was 1 sand, 3 gravel and sand (50% each) and 6 broken stone laid wet. In all there were 4,833 cu. yds., including wing walls and parapets. The work was done by company forces at Elkhart, Ind., in 1903. It will be noted that the sand and stone were unusually low in cost.

	Total cost.	Cost per cu. yd.
Cement	$ 8,860	$1.84
Stone	1,789	0.36
Sand and gravel (obtained from foundations)	240	0.05
Drain tile	103	0.02
Steel rods	3,028	0.63
Labor on concrete	8,091	1.68
Engineering and watching	508	0.11
Arch centers and forms	3,529	0.73
Sheet piling and boxing	1,006	0.21
Excavating and pumping	1,620	0.33
Machinery, pipe, fittings, etc	416	0.08
Temporary buildings, trestles, etc	752	0.15
Total for 4,833 cu. yds	$29,942	$6.19

Cost of Small Reinforced Concrete Highway Bridges.*—Reinforced concrete highway bridge construction is being widely advocated by

*Engineering-Contracting, Dec. 2, 1908.

the Illinois Highway Commissioner, Mr. A. N. Johnson, State Engineer. To encourage the building of such bridges, he has worked out two general standard designs. He recommends reinforced concrete for all spans under 50 ft. in length. It has found that for

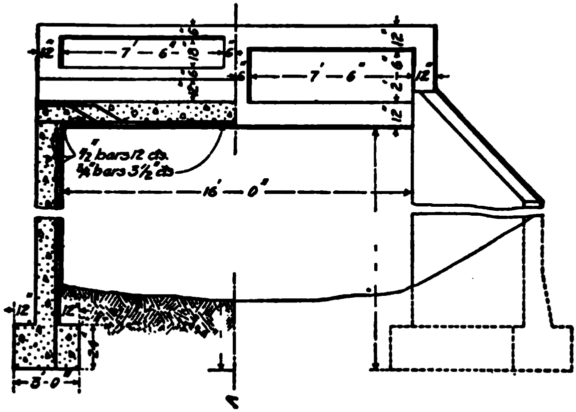


Fig. 16.

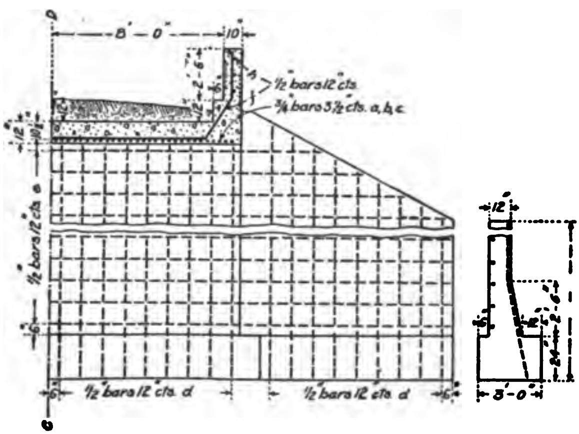


Fig. 17.

spans under 40 or 50 ft., reinforced concrete can be used at very reasonable cost and that for longer spans a reinforced concrete floor does not add an excessive amount to the cost of the bridge.

***Spans Under 18 Ft.*—For spans under 18 ft. in the clear a plain reinforced concrete slab is used for the floor, the principal rein-**

forcement running from abutment to abutment. Reinforced concrete side rails are used for this class of bridge and are considered preferable to pipe or angle rails because of their strength and durability. Figures 16, 17 and 18 show the plans for one of these bridges. In constructing these bridges Mr. Johnson says:

"Where a number of slab bridges under 20 ft. in span are built the same season, it may prove cheaper to use I-beams to support the slab until the concrete has set than to use mud sills and timber posts. If this is done the abutments are carried up as usual to the height of the under side of the floor, pockets being left for the I-beams; these pockets being about 6 ins. wide and deep enough so that when opposing wedges are placed under the ends of the I-beams the top flanges of the I-beams will be 2 ins. below the

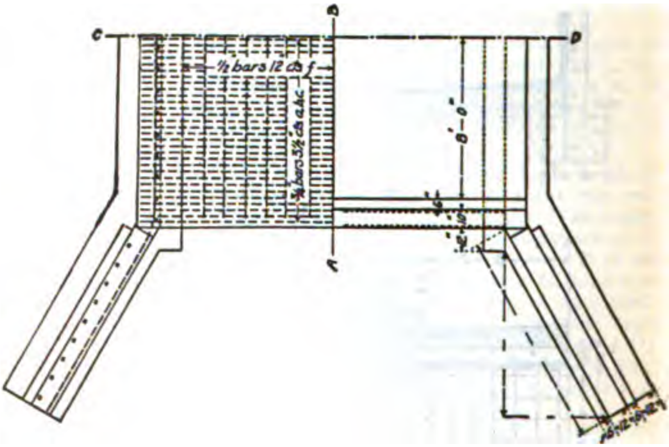


Fig. 18.

level of the bottom of the slab. Two-in. planking is used to support the slab. When the concrete in the slab and rails has hardened sufficiently the wedges are removed and the floor forms drop down; the planks are drawn out at the sides and likewise the I-beams through the pockets in one of the abutments. The pockets are then filled with concrete. The I-beams and planks may be used repeatedly."

Spans From 18 to 42 Ft.—For spans ranging in length from 18 to 42 ft. the concrete rails have been designed as girders to carry the load to the abutments. The floor in this case is a reinforced concrete slab, the main reinforcement running from girder to girder. The floor is suspended to the girders by bending every third floor bar up into the girders. This type might well be classed as a reinforced concrete through girder bridge. This has proved to be a very economical design. The forms are very simple and much

of the lumber remains uncut. The bending moment in the floor slab is independent of the length of the span, and consequently the amount of concrete and steel in the floor slab, for a given width of roadway, remains constant per foot of bridge. The rails or girders for bridges 18 to 30 ft. in span contain but little more concrete than would ordinarily be necessary for appearance and economical placing in the rail forms. For spans over 30 ft., and particularly for wide roadways, the girders become heavier, and it has been found necessary to design the girders with a heavy coping, giving the girders a *T*-beam section. A number of girder bridges of this character have already been built and the plans drawn for several which will be built the coming season.

The dimensions, quantities and costs for a number of the bridges built on these plans are given in Table XXI.

Cost of a Reinforced Concrete Highway Bridge.—The bridge had a clear span of 30 ft. and an 80-ft. roadway. The arch ring was 8 ins. thick at the crown and 12 ins. thick at skewbacks, with a rise of approximately 6 ft. It rested on 12-in. abutment walls, with center posts and 21-in. footing slabs. The spandrel walls were 12 ins. thick and reached well beyond the abutment walls on each side, the free ends having inside counterforts. The height of the abutment walls from skewback to water level was 12 ft. These walls were continued beyond the faces of the spandrel walls by wing walls, which held the slopes of the deep fill from the channel. This fill reached to a height of 4 ft. above the crown of the arches. All walls were founded on piles. There were 872 cu. yds. of concrete in the structure. The general design was made by City Engineer M. P. Blair, St. Boniface, Manitoba, where the bridge was built and the reinforcement was designed and supplied by Clarence W. Noble, Winnipeg, Manitoba. The reinforcement was high carbon square twisted steel bars. The work was done by day labor by the city engineer and cost as follows:

Foundations—	Total Cost.
5,336 cu. yds. excavation, at 38.2 cts.	$2,034.63
6,060 lin. ft. piling, at 14.7 cts.	893.85
Driving piles at 15½ cts. per lin. ft. (by contract)	939.30
Total	$3,867.78

Concrete Materials—	Total.	Per-cu. yd.
1,446 bbls. cement, at $2.45	$3,543	$4.063
872 cu. yds. aggregate f. o. b. cars at $1	872	1.000
Lumber for forms, etc. (1/3 of $1,491)	497	0.570
Reinforcing bars	1,418	1.626
Totals	$6,330	$7.259

TABLE XXI.

Span in ft.	Height of Abut-ment, ft.	Width of Road-way, ft.	—Superstructure.— Concrete, cu. yds.	Steel, lbs.	—Substructure.— Concrete. cu. yds.	Steel, lbs.	—Total.— Concrete cu. yds.	Steel, lbs.	Cost.	Cost per lin. ft.
16	12	18	23.5	3,142	75.2	2,385	98.7	5,527	$1,146	$71.64
8	7	18	....	.....	....	.....	38	816	245	30.62
4	7.5	16	....	.....	....	.....	16.9	229	120	30.00
15	9.5	16	....	.....	....	.....	56	3,000	610	40.66
27.5	13	16	27.7	6,158	....	.....	27.7	6,158	460	16.72
15	8.5	18	....	.....	....	.....	42.1	3,435	640	42.66
40	14	16	....	.....	....	.....	139	14,050	2,221	55.52
30	12	16	34.5	7,449	58.6	2,006	93.1	9,455	1,380	46.00
12	14	16	10.2	1,479	55.3	1,741	65.5	3,220	695	57.91
3	5	20	3.3	240	13.2	.....	16.5	240	123	41.00
12	9	16	10.3	1,489	35.7	977	46	2,466	419	34.08
20	12.5	14	22.7	3,508	....	.....	22.7	3,503	262	13.10
30	14	16	....	.....	....	.....	90.6	8,630	935	33.16
14	10	16	14.9	3,019	43.4	1,029	58.3	4,046	750	53.57
30	15	16	34.5	7,449	71.8	2,558	106.3	10,007	1,154	38.46
10	8.5	16	8.1	1,132	22.5	803	30.6	1,935	390	39.00
16	6.5	16	16	2,294	26.7	556	42.7	2,850	409	25.56
12	..	16	10.3	1,480	....	.....	10.3	1,480	198	16.50

Labor—		
Labor on forms	$ 652	$0.74
Placing reinforcement	129	0.148
Hauling aggregates	323	0.371
Mixing and placing concrete	1,408	1.614
Finishing concrete work	56	0.064
Erection of mixer	61	0.070
Totals	$2,629	$3.007
Supplies—		
Coal	$ 24	$0.027
Oil for forms	31	0.035
Totals	$55	$0.062
Grand totals for concrete work	$9,014	$10.335

The work was carried on under considerable difficulty. The excavation was interrupted by frequent rains, and the banks slipped, causing the handling of considerable additional material. The work of driving piles was also frequently interrupted by rain, and as a consequence the extra work of placing concrete did not start until late in the fall, and had to be prosecuted by two shifts, working day and night, Sunday included, until it was finished. The conditions are reflected in the high unit cost of excavation. The cost of placing reinforcing bars is about typical, while the cost of placing concrete at $1.61 per yard is abnormal, owing to the fact that in this item is charged considerable general labor, which could not be otherwise apportioned.

The specifications originally contemplated the use of crushed limestone, but there was submitted to the engineer samples of very good gravel at a price of $1 per cu. yd. This gravel was clean, and contained enough sand to fill the voids without additional material; in fact, some of it contained slightly too much sand. The cost of sifting out the coarse material and again sifting out the fine material, and then mixing the two together in the proper proportions was found to be 32 cts. per cu. yd. This was used for all arch concrete, but for abutments the mix of the gravel as delivered was deemed satisfactory, as it did not vary greatly from the proper proportions. The footings were made of crusher rock dust and limestone, which had been owned by the city for several years. This material is considered as costing the same as gravel.

Cost of Mixing and Placing Concrete for an Arch Bridge.—A natural mixture of sand and gravel was brought in on trucks *AA* by electric railway and discharged through gratings into a storage bin, Fig. 19. Five parallel charging car tracks *BB* ran under this storage bin. The charging cars *C* were 16 cu. ft. capacity, just one batch for the mixer. A car was first loaded with gravel under one of the hoppers, then moved back under the cement chute to receive the cement, and then moved forward onto the truck *F* which traveled on the transverse track passing the mixer. The mixer discharged into a hoist bucket *I* which automatically discharged its load into the hoppers *JJ* whence the concrete was chuted into wheelbarrows, two wheeled carts or dump cars and taken out on

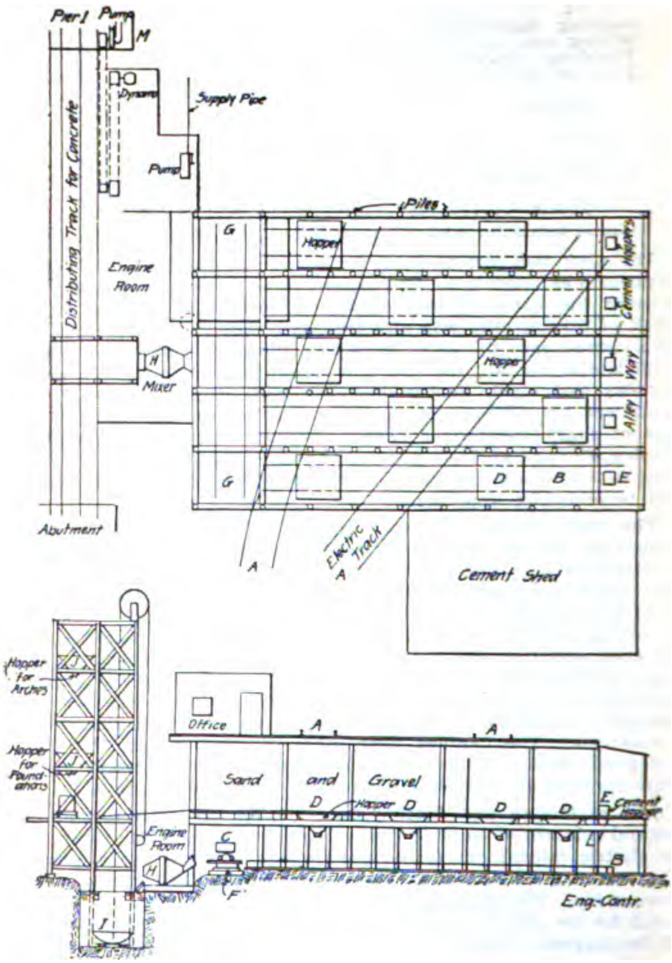


Fig. 19.—Concrete Mixing Plant.

trestles to the work. The gang charging and mixing and placing the concrete was as follows:

Duty.	No. men.
Charging cars	3
Cement	1
Operating mixer	2
At hopper in tower	1
Wheeling concrete	3 to 5
Placing and spading concrete	3
Hoist engineer	1
Fireman (mixer and pump)	1
Total	15 to 17

This gang placed on an average 150 cu. yds. of concrete per day, or about 10 cu. yds. per man. With wages averaging $2 per man per day this would give a labor cost of 20 cts. per cu. yd. for mixing and placing, not including superintendence.

Cost of a Reinforced Concrete Arch Bridge.—In *Engineering-Contracting*, July 22, 1908, Mr. John Harms gives the following data: The bridge has a roadway 30 ft. wide in the clear, and two sidewalks 8 ft. wide each. The length of the bridge is 306 ft.

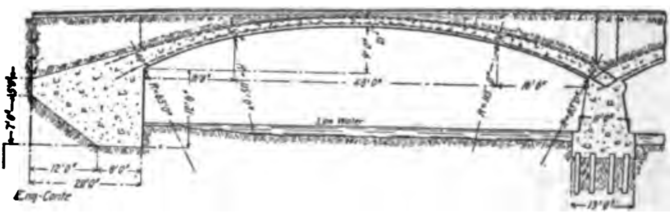


Fig. 20.—Concrete Arch Bridge.

divided as follows: 20 ft. for each abutment, 81 ft. for each outer arch, 88 ft. for center arch and 8 ft. for each pier. The reinforcement used in the arches is 1 in. twisted steel, 2 ft. c. to c. in two rows, 1½ ins. from extrados and intrados and tied to ½ in. square transverse rods every 5 ft. The reinforcement of the overhanging sidewalks is of expanded metal No. 4 gage 6 in. mesh, which is turned down at the outer edge for about 4 ins. and fastened to a ¾ in. square rod, and on the inner edge is hooked to a 1 in. twisted rod which is anchored with ½ in. twisted rods to the bottom reinforcing rods of the arch, as shown by Figs. 20 and 21.

The thickness of concrete of the arches is 40 ins. for the outer arches at haunches, 30 ins. at a distance of 16.5 ft. from haunches and 21 ins. at the crown. For center of the arch the thickness is 42 ins. at haunches, 30 ins. at distances of 16.5 ft. from haunches and 22 ins. at the crown.

The piers are of monolithic construction. The upstream and downstream ends form a sharp point, reinforced with blocks of brown stone, cut to the proper angle to break the ice. Piers and

abutments were built up to an elevation of 9.5 ft. above low water mark. Since the bed of the river is soft mud, each of the piers was built on a foundation of 60 piles driven 3 ft. c. to c. and cut off at an elevation of 2 ft. below M. L. W.

On account of the kind of soil it was necessary to drive piles for the falsework, and this was begun at the same time as the jetting for the sheetpiling of the abutment. The piles for falsework consisted of nine rows of five piles each for outer arches, and ten rows for center arch. After piles for first arch were driven, pile driving for pier No. 1 was started. This being finished, jetting of sheetpiling for the pier was started. Up to this time the

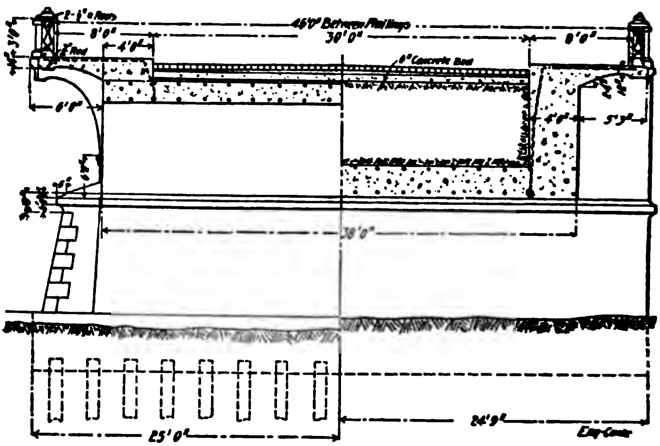


Fig. 21.—Cross-Section of Bridge.

water in the river was as low as 2 ft., making it impossible to float any craft, and so cribwork had been used for handling the pile driver. Heavy rainfalls raised the water to 10 ft. and caused at times such strong currents that the work had to be stopped. This brought the cost of labor much higher than it would have been under ordinary circumstances. The cost of jetting the sheetpiling on the pier is given further on. After the sheetpiling was all driven and properly shored for heavy water pressure a centrifugal pump was installed, driven by the pile driver engine, and the enclosure was kept dry until concrete was in place. Excavation was extended to 3 ft. below low water mark and the piles cut off 2 ft. below the same level, so as to enclose them in about 12 ins. of concrete. The whole space was then filled in with concrete up to M. L. W., and on this foundation the forms for the pier were built.

At this time excavation for abutment No. 1 was finished and a Koppel industrial railway had been laid. This railway was laid

on a temporary trestle across the river and was provided with switches to reach abutments and piers.

Sheetpiling of the abutments served as forms up to about 4 ft. below the spring line. Above this point, forms of 2 in. spruce were built. The designing of an 18-in. crown molding on all piers and abutments at the height of the spring line of arches made the forms rather expensive. The concrete in the abutment was finished in broken layers on the arch side to give a good bond between arch and abutment. While the concreting on abutments and piers was being done, the building of falsework for the first arch had proceeded.

The construction of this falsework was as follows: Piles were cut off at a height of 3 ft. below the bottom line of the concrete

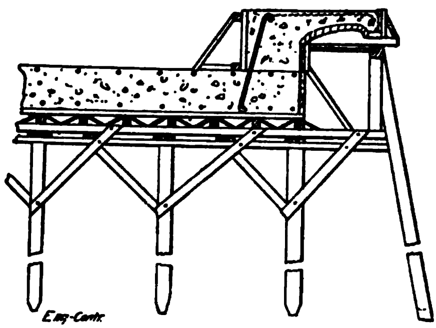


Fig. 22.—Falsework and Forms.

arch. On these piles were placed, transverse to the arch, two 6 x 12-in. caps, spiked to piles well spliced together at joint in center, and overhanging about 6 ft. at outside. An upper cap was made of two 6 x 12-in. timbers. Between the two caps oak wedges were placed about every 5 ft. On top of the upper caps were placed 3 x 12-in. floor beams 2 ft. 8 in. c. to c., cut on top to proper line of arch. A 2-in. spruce floor was nailed to these floor beams (see Fig. 22).

It may be well to remark here that the centers were laid out full size on a large platform, and patterns were made of 1-in. pine boards for all floor beams and side forms of arches. The cutting of all the floor beams was done by a 12-in. circular saw, which was run by a belt connected to the hoisting engine which pulled the cars up the incline to the mixing platform.

The different radii of the arches made the curves of the floor beams vary to such an extent that the amount of framing of center done per day varied a great deal. The side forms of arches were made of 2-in. spruce and built in sections of 7 ft. In this way the

placing of forms was done quickly and cheaply. The specifications stated that the concreting of the arches should be done in ribs of such a width that one complete rib of the arch could be finished in a day. Three more forms similar to the outside forms were made and so placed as to divide the arch into five equal ribs.

Since it is important to have reinforcement at the proper distance from intrados and extrados, little cement blocks of 1½-in. thickness were made to hold the bars at the proper distance from the bottom. The advantage of using concrete blocks instead of wooden blocks, as is usually done, is easily understood. The blocks, being of concrete, stay in place, require no pointing up afterwards, and the cost of making them is about ½ ct. each.

After placing, upper longitudinal bars, sticks were used to hold these in place, but the writer proposes on future jobs to make concrete blocks as shown in Fig. 23. The cost of such a block the writer believes would be small, while its efficiency would be such as to make it economical.

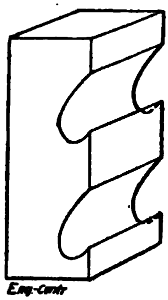


Fig. 23.

As shown in plan, Fig. 21, the reinforcement of spandrel walls and overhung sidewalk was anchored to the lower rods or arch, and the 1-in. rod was suspended at the proper height on wooden brackets nailed to the outside of the arch forms. From this bar, ½-in. twisted rods were run to the lower rods, every 18 ins., being hooked on both rods by turning the ends.

Pile driving and sheetpiling had been going on, and when high water caused this work to be stopped, concreting of abutment No. 2 was done.

The industrial railway proved of great value during all this time for handling materials in an economical way.

It may be well to mention the method used for handling the materials. The stone and sand had to be stored on building lots about 250 ft. away from the proposed bridge. A platform 14 x 16 ft. was built about 60 ft. from this place at an elevation of 16 ft. Under this platform was placed a Smith mixer, blocked up on timbers, high enough to allow of dumping into the Koppel side

dumping cars. A timber trestle was built extending from stone and sand pile to the top of the platform and an industrial railway laid on this. Cars were pulled up the incline by a hoisting engine stationed back of the mixer. See Fig. 24. A switch was placed at the bottom of the incline, making it possible to work two cars. Those cars were marked to give the proper quantities of sand and stone for a ½ batch proportioned 1 : 3 : 6. Atlas cement was used and as it was taken from the storage house it was put on the cars in bags enough for every batch, and opened and emptied at the platform. Each car furnished also all the materials required, and in this way an output was obtained of 35 to 40 batches per hour. Starting from the mixer was the other industrial railway previously mentioned. The elevation of track at the mixer was 14 ft. 3 ins. above M. L. W. The tracks had a down grade of about 4 ft. to a length of 150 ft.

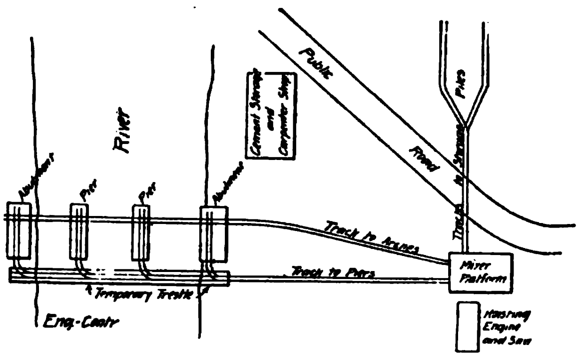


Fig. 24.

This brought the rails at the proper height for dumping concrete into piers and abutments, and at the same time, gave the cars enough momentum to require but little pushing.

After finishing the piers and abutments to the spring line, the track was removed and laid to the arches. Heavy timber was placed across the arch forms on which were laid longitudinal timber to carry tracks. At the crown of the first arch the track was elevated and cars were pulled up this grade by the hoisting engine, from which point they proceeded by their own momentum. On the crowns of the first and center arches, switches were put in, and by this arrangement three cars were handled so rapidly that at no time did the mixer have to stop on account of there not being cars available.

The plant proved sufficient to do the work in remarkably short time. The time from beginning concreting of first arch until the third was finished, including the erection of all falsework and

forms for the last two arches, was only 29 days. All the concrete was placed in 15 days, working not longer than 7 hours a day. If four ribs instead of five had been made in each arch, the results would have been even better, but this would have meant taking a great risk, on account of doubtful weather at this season of the year and also in case of any breakdown of machinery.

The building of falsework for the spandrel wall and overhanging sidewalk proved difficult and was by far the most expensive of all form work.

This falsework was constructed by resting one side on posts placed on the caps of the falsework of the arches, while the other side was held up by posts placed at a slight angle and rammed in the mud of the river bottom. These posts and the caps on them were 8 x 10-in. timbers. On these caps 3 x 12-in. floor beams were placed 3 ft. c. to c., being covered with 2-in. spruce flooring, cut into 4-in. strips, the edges being tapered to make tight joints. The whole falsework was well braced. At all corners of forms, molding was nailed to the forms to round off the corners of the concrete. Panel effects in the concrete were also made by nailing battens to the forms. These pieces were generally planed.

Each arch had expansion joints of ⅜ in. at both ends and also at a distance of 24 ft. 3 ins. from both ends. Each expansion joint was made up of ¼-in. corrugated paper covered on both sides with 3-ply tar paper.

Balusters.—The balusters for the railway were all made on the job, there being 350 required, and for this purpose eight forms were made. These were made in four parts each and were held together with bolts so that removing the form was easily done.

The base of these balusters was 8 x 8 ins., the height being 2 ft. As previously stated, eight forms were made for this work. The forms were made on the job. The entire labor cost of making the balusters was:

Carving white wood blocks, 1 man, 12 days, at $3..	$ 36.00
Making 8 forms, 1 man, 12 days, at $2.75	33.00
Making and finishing balusters, 1 man, 35 days, at $2.75	96.25
Total	$165.25

A man made 10 balusters per day. The cost for forms was 19.7 cts. per baluster, and for making and finishing, each 27.5 cts., giving a total cost for labor of 47.2 cts.

Sheet Piles.—In jetting down the sheet piles, which were 2 x 8 ins. x 20 ft. long on an average, 100 pieces were put in place per day, or 1 piece every 6 minutes. This does not include moving machine from one pier to another, but does include moves while working on a single pier. The labor cost was:

1 Foreman	$ 5.00
1 Engineman	3.50
2 Hosemen, at $3.50	7.00
2 Men preparing piles, at $2.50	5.00
7 Helpers, at $1.75	12.25
Total	$32.75

There being 2,000 lin. ft. of piling or 2,666 ft. B. M. gives a unit cost of 1 6/10 cts. per lin. ft. and $12.25 per M. ft. B. M. for the labor.

Forms.—The labor costs for forms for the spandrel wall and overhanging sidewalk on the two sides of an arch were:

Foreman carpenter, at $5	$ 20.00
Building falsework:	
2 Carpenters, at $3.50	28.00
3 Men, at $2	24.00
Building forms:	
2 Carpenters, at $3.50	28.00
6 Carpenters, at $3	75.00
2 Carpenters, at $2.75	22.00
3 Helpers, at $2	26.00
Total	$223.00

There was about 12,000 ft. B. M. of lumber used in these forms, thus giving a cost of framing and erecting per M ft. B. M. of $18.60. With 180 cu. yds. of concrete put in these forms the cost per cu. yd. was $1.24 for the labor on the forms.

The cost of erecting the forms for the arch, exclusive of the piling, was:

Foreman carpenter, 6 days, at $5		$ 30.00
Falsework, 8,300 ft. B. M., erecting crew:		
2 Men, at $3.50	$ 7.00	
2 Men, at $2.50	5.00	
2 Men, at $2.00	4.00	
2 Men, at $1.75	3.50	
Total, 4 days, at	$19.50	78.00
Floor beams, 5,960 ft. B. M., carpenter crew:		
2 Men, at $3.50	$ 7.00	
4 Men, at $3.00	12.00	
3 Men, at $2.75	8.25	
1 Man, at $2.00	2.00	
2 Men, at $1.75	3.50	
Total, 2 days, at	$32.75	65.50
Erecting crews, 2 days, at $19.50		39.00
Forms, bottom and sides, 11,000 ft. B. M., carpenter crew:		
Framing forms, 2 days, at $32.75		98.25
Setting forms, 2 days, at $32.75		65.50
1 man making patterns, 3 days, at $3.50		10.50
Total		$386.75

There was 25,000 ft. B. M. of lumber in the falsework and forms exclusive of the piles, which makes a cost per M ft. B. M. of $15.47 for this labor. As there was 365 cu. yds. in an arch this gave a cost of $1.06 per cu. yd. for this labor.

Concrete.—In mixing and placing the concrete for the arches, one rib was done in a day so that it would be monolithic. There

were 73 cu. yds. in a rib. The following was the cost of labor per day when mixing and placing was being done:

1	Foreman	$ 5.00
1	Sub-foreman	3.50
1	Engineman	3.50
1	Man running mixer	2.50
1	Concrete placer	2.75
4	Concrete placers, at $2.50	10.00
6	Men on cars, at $2	7.80
2	Men on mixer platform, at $2	4.00
1	Man at stock pile	2.00
22	Men shoveling, at $1.75	38.50
	Total	$79.55

The actual time of placing a ring was from 6 to 7 hrs., thus giving a cost of mixing and placing of 85 cts. per cu. yd. When the concrete work was done, some of the crew was knocked off, and the rest were kept busy in changing tracks and other details. As stated, a larger ring could have been placed in a day, but the

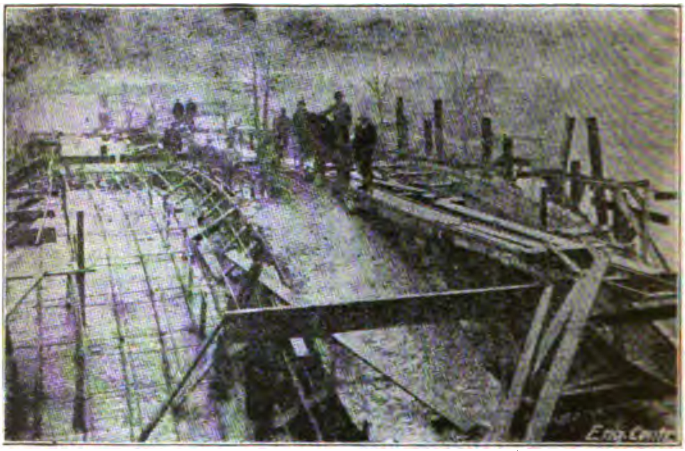


Fig. 25.—Casting Concrete Arch Rings.

risk of some unforeseen accident that might have held up the work was considered too great to take. Fig. 25 shows how these rings were cast.

Cost of a Concrete Ribbed Arch Bridge at Grand Rapids, Mich.*— The bridge consisted of seven parabolic arch ribs of 75 ft. clear span and 14 ft. rise. The five ribs under the 21-ft. roadway were 24 ins. thick, 50 ins. deep at skewbacks and 25 ins. deep at crown;

**Engineering-Contracting,* Jan. 8, 1908.

the two ribs under the sidewalks were 12 ins. thick and of the same depth as the main ribs. Each rib carried columns which supported the deck slab. Columns and ribs were bound together across bridge by struts and webs. All structural parts of the bridge were of concrete reinforced by corrugated bars. The abutments were hollow boxes with reinforced concrete shells tied in by buttresses and filled with earth. There were in the bridge including abutments 884 cu. yds. of concrete and 62,000 lbs. of reinforcing metal or about 70 lbs. of reinforcing metal per cu. yd. of concrete. Of the 884 cu. yds. of concrete 594 cu. yds. were contained in the abutments and wing walls and 290 cu. yds. in the remainder of the structure.

Centers.—The center for the arch consisted of 4-pile bents spaced about 12 ft. apart in the line of the bridge. The piles were 12 x 12 in. x 24 ft. yellow pine and they were braced together in both directions by 2 x 10-in. planks. Each bent carried a 3 x 12-in. plank cup. Maple folding wedges were set on these cups over each pile and on them rested 12 x 12-in. transverse timbers one directly over each bent. These 12 x 12-in. transverse timbers carried the back pieces cut to the curve of the arch. The back pieces were 2 x 12-in. plank, two under each sidewalk rib and four under each main rib of the arch. The back pieces under each rib were X-braced together. The lagging was made continuous under the ribs but only occasional strips were carried across the spaces between ribs. This reduced the amount of lagging required but made working on the center more difficult and resulted in loss of tools from dropping through the openings. Work on the centers and forms was tiresome owing both to the difficulty of moving around on the lagging and to the cramped positions in which the men labored. Carpenters were hard to keep for these reasons.

Concrete.—A 1 : 7 bank gravel concrete was used for the abutments and a 1 : 5 bank gravel concrete for the other parts of the bridge. The concrete was mixed in a cubical mixer operated by electric motor and located at one end of the bridge. The mixed concrete was taken to the forms in wheelbarrows. The mixture was of mushy consistency. No mortar facing was used but the exposed surfaces were given a great work. In freezing weather the gravel and water were heated to a temperature of about 100° F.; when work was stopped at night it was covered with tarred felt and was usually found steaming the next morning.

The cost data given here are based on figures furnished to us by Geo. J. Davis, Jr., who designed the bridge and kept the cost records. Mr. Davis states that the unit costs are high, because of the adverse conditions under which the work was performed. The work was done by day labor by the city, the men were all new to this class of work, the weather was cold and there was high water to interfere, and work was begun before plans for the bridge had been completed so that the superintendent could not intelligently plan the work ahead. Cost keeping was begun only after the work was well under way. Many of the items of cost were incomplete in detail.

The following were the wages paid and the prices of the materials used:

Materials and Supplies—

No. 1 hemlock matched per 1,000 ft.	$20.00
No. 1 hemlock plank per 1,000 ft.	17.00
No. 2 Norway pine flooring per 1,000 ft.	19.00
No. 2 yellow pine flooring per 1,000 ft.	20.00
12 x 12 in. x 16 ft. yellow pine per 1,000 ft.	29.00
12 x 12 in. x 24 ft. yellow pine piling per 1,000 ft.	27.00
Maple wedges per pair	.50
½-in. corrugated bars per 100 lbs.	2.615
¾-in. corrugated bars per 100 lbs.	2.515
⅞-in. corrugated bars per 100 lbs.	2.515
Coal per ton	4.00
Electric power per kilowatt	.06
Medusa cement per bbl.	1.75
Ætna cement per bbl.	1.05
Bank gravel per cu. yd.	.85
Sand per cu. yd.	.66
Carpenters, per day	$3 to 3.50
Common labor, per day	1.75

The summarized cost of the whole work, with such additional costs as the figures given permit of computation, was as follows:

General Services—	Total.	Cu. Yd.
Engineering	$451	$0.512
Miscellaneous	75	0.084

Pumping—

Coal at $4 per ton	$210
Machinery, tools and cartage	283
Labor	497
Total, 110 days, at $9	$990

Excavation—	Total Cost.
Timber, cartage, etc.	$ 375
Tools	69
Labor at $1.75	1,687
Total	$2,131

Filling (5,711 cu. yds.)—	Total.	Per cu. yd.
Earth	$1,142	$0.20
Labor, including ripraping	396	0.07
Total	$1,538	$0.27

Removing Old Wing Walls—	Total.
Labor and dynamite	$346
Tools and sharpening	64
Total	$410

Hand Rail (150 ft.)—	Total.	Per lin ft.
Material	$278	$1.85
Labor	29	0.19
Total	$307	$2.04

Wood Block Pavement (296 sq. yds.)—	Total.	Per sq. yd.
Wood block, etc.	$695	$2.35
Labor	57	0.19
Total	$752	$2.54

Steel (62,000 lbs.)—	Total.	Per. lb.
Corrugated bars, freight, etc.	$1,498	2.41c
Plain steel, wire, etc.	75	0.12c
Blacksmithing, tools and placing	438	0.71c
Total	$2,011	3.24c

Centering—	Total.	Per cu. yd. Concrete.
Lumber and poles	$332	$1.14
Labor	272	0.95
Total	$604	$2.09

	Total.	Per cu. yd.
Forms	$ 3,312	$ 3.75
Concrete	$ 5,532	$ 6.25
Grand total	$18,113	$20.50

In more detail the cost of the various items of concrete work was as follows for the whole structure, including abutments, wing walls and arch, containing 884 cu. yds.:

Form Construction—	Total.	Per cu. yd.
Lumber and cartage	$1,547	$1.75
Nails and bolts	129	0.15
Tools	110	0.12
Labor, erecting and removing	1,526	1.72
Total	$3,312	$3.74
Concrete Construction—Materials—		
Medusa cement, at $1.05	$1,218	$1.37
Ætna cement, at $1.75	499	0.56
Sand, at 66 cts. per cu. yd.	37	0.04
Gravel, at 85 cts. per cu. yd.	915	1.04
Total materials	$2,669	$3.01
Mixing—		
Machinery and supplies	$ 569	$0.62
Power, at 6 cts. per kw.	52	0.06
Tools	22	0.02
Labor	737	0.83
Total mixing	$1,360	$1.53
Placing concrete	$ 609	$0.69
Tamping concrete	$ 481	$0.54

Heating Concrete—		
Apparatus and cartage	$ 47	$0.05
Fuel	96	0.11
Labor	270	0.31
Total heating	$ 413	$0.47
Grand total	$8,844	$9.98

Considering the abutment and wing wall work, comprising 594 cu. yds., separately, the cost was as follows:

	Per cu. yd.
Forms—	
Materials	$1.20
Labor	1.09
Total	$2.29
Concrete—	
Materials	$2.92
Labor	2.38
Total	$5.30
Heating water and gravel	$0.70
Grand total	$8.29

Considering the arch span, comprising 290 cu. yds., separately, the cost was as follows:

	Per cu. yd.
Forms—	
Materials	$ 3.70
Labor	3.03
Total	$ 6.73
Concrete—	
Materials	$ 3.32
Labor	3.57
Total	$ 6.79
Grand total	$13.52

Cost of Centering of a 233-ft. Arch.—In *Engineering-Contracting*, Jan. 6, 1909, are given design and data relating to the Walnut Lane Bridge, Philadelphia, as furnished by Mr. George H. Heller. Only a brief summary of the article is given here.

Dimensions of Arch.—The main arch of the Walnut Lane bridge consists of two arch ribs, each 18 ft. wide at the crown and 21 ft. 6 ins. wide at the skewback; these ribs are spaced 34 ft. c. to c., and are 5 ft. 6 ins. deep at the crown and 9 ft. 6 ins. deep at the skewback; the span is 233 ft. in the clear, and the height of the soffit at the crown above the springing line is 70 ft. 3 ins.

The two main ribs carry spandrel piers and a series of spandrel arches upon which the spandrel walls are built up to the height to receive the floor, which consists of steel beams with concrete arches between, and it is upon this floor that the roadway and sidewalk paving is laid, the roadway being 40 ft. wide and the two sidewalks each 8 ft. wide. The height of the soffit of the arch above the surface of the creek is about 136 ft., while the roadway of the bridge is about 14 ft. higher, making about 150 ft.

It is necessary, while considering the nature of the design (Fig. 26), to remark the fact of the arch itself being composed

of two independent and separate ribs. This feature allowed the construction of each rib by itself and so presented an opportunity of reducing the cost of the centering by permitting one arch rib to be constructed first on centering necessary for one rib, and then, when the arch is completed, to move the same centering transversely so as to serve for the construction of the adjacent arch rib. This feature of construction was embodied in the design, and it was found not only to be feasible but also simple and easy of action, even though the mass of timbering was so great and covered so large an area. It was also thought proper to use steel in the construction of the bottom of the centering, for, as a material, it afforded better facilities for making joints capable of withstanding possible vibration in moving, and it formed a firm foundation, all parts of which acted together as a unit and allowed the whole mass to be moved true to line and without distortion or accident to its new position.

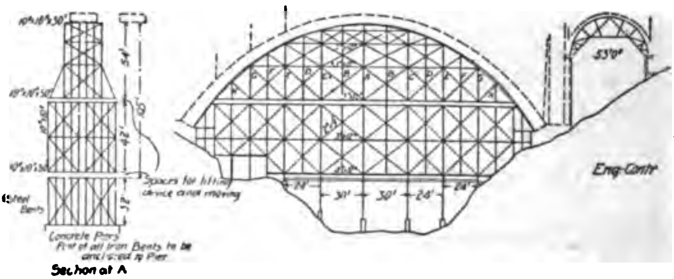


Fig. 26.—Centering for Walnut Lane Bridge.

Beginning with the base of the centering, the steel trestle supports were spaced 24 ft. and 30 ft. apart and were carried on concrete piers founded upon and doweled into the solid rock. These piers were carried up to a uniform height above all danger of freshet, and they formed the basic foundation upon which the whole mass of steel and timber was designed to move. Each steel trestle was securely anchored into its pier by 1½-in. steel rods, and these rods served to guard against freshets and wind and were released when the centering was moved.

The movement of the centering was accomplished by placing on each pier a series of ten steel rollers, each 6 ins. in diameter, rolling on steel plates built into the tops of the piers; each roller was capable of bearing in safety 10 tons, making 100 tons, which was the total maximum weight at the center pier to be moved. The steel bents rested upon these rollers, and upon completion of the erection of one rib of the arch they were all moved in unison by placing jacks between the bottom end of each steel bent and a studded anchor chain which formed a cradle or saddle against which

the jack worked, the ends of the chain being attached to timbers previously built into the piers for that purpose; this method of translation proved to be quite effective, and the whole distance of 34 ft. was covered in the space of three days.

The total weight moved can be fairly stated to be about 1,000 tons. This amount is found by taking the total weight of bolts, steel trestle and timber trestle, and allowing in the case of timber 5 lbs. per ft. B. M., the timber being probably very heavy from the absorption of water from the structure. This great weight, covering a length of say, 230 ft., and a width of 50 ft., was moved by jacks having a sum total capacity of 345 tons acting at 15 points.

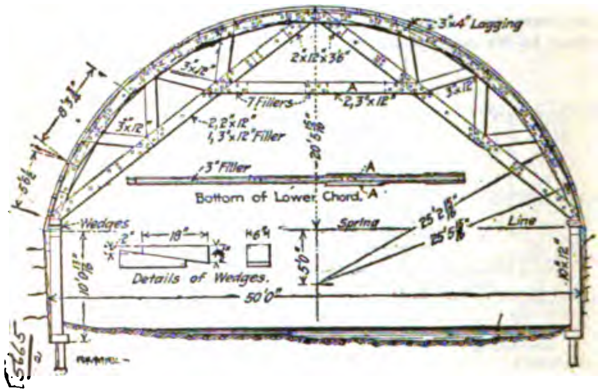


Fig. 27.—Arch Centers.

The quantities of material used in the construction of the centering were:

Bolts, washers, nails	33,000	lbs.
Steel trestle and its floor	232,000	lbs.
Lagging and joists	88,000	ft. B. M.
Upper trestle and bracing	116,000	ft. B. M.
Lower staging and bracing	136,000	ft. B. M.
Concrete piers	1,000	cu. yds.

The cost was:

Timber	340,000 ft. B. M. at	$65.00	$22,100
Metal	265,000 lbs.	.04	10,600
Masonry	1,000 cu. yds.	10.00	10,000
Total			$42,700

This centering served for two ribs, each containing 1,550 cu. yds., or a total of 3,100 cu. yds. Hence the centering cost $13.80 per cu. yd. of concrete ribs.

The contract price for the Walnut Lane bridge was $262,000.

Design of Center for a 50-ft. Span Masonry Arch.*—With the present high prices of lumber, the designing of timber centers for arches becomes a problem that requires careful study to save material and labor. In the accompanying drawing we show a center designed for a 50-ft. masonry arch railway bridge to be built in central Ohio. Owing to the excessive cost of pine in this section, oak will be used. This timber costs here about $16 per M ft. B. M. The center, 36 ft. long, comprising two arch ribs, posts, cups, wedges and lagging, calls for 16,464 ft. B. M. of timber divided as follows:

		B. M.
	3 x 4 ins. x 4 ft. lagging	1,554 ft.
140	2 x 12 ins. x 8 ft. 3¾ ins. straight ribs	2,332 ft.
20	2 x 12 ins. x 5 ft. 6½ ins. straight ribs	222 ft.
20	2 x 12 ins. x 2 ft. 9¼ ins. straight ribs	112 ft.
20	3 x 12 ins. x 7 ft curved ribs	420 ft.
60	3 x 12 ins. x 8 ft. curved ribs	1,440 ft.
40	3 x 12 ins. x 7 ft. braces	840 ft.
40	3 x 12 ins. x 7 ft. 6 ins. braces	900 ft.
10	2 x 12 ins x 26 ft. bottom chord	1,920 ft.
40	2 x 12 ins. x 24 ft. bottom chord	520 ft.
40	3 x 12 ins. x 11½ ft. fillers bottom chord	1,380 ft.
20	3 x 12 ins. x 7 ft. fillers bottom chord	420 ft.
20	3 x 12 ins. x 21 ft. piece A	1,260 ft.
40	2 x 12 ins. x 3½ ft. bottom chord end con.	280 ft.
20	10 x 12 ins. x 9 ft. posts	1,800 ft.
2	6 x 12 ins. x 38 ft. wall plates	456 ft.
2	8 x 12 ins. x 38 ft. caps	608 ft.
	Total	16,464 ft.

660 ¾ x 9 in. bolts for ribs.
320 ¾ x 9 in. bolts for bottom chord.
120 ¾ x 13 in. bolts for end con. bottom chord.
160 ¾ x 15 in. bolts for piece A.

Figure 27 shows the framing very clearly. With carpenters receiving $4 per day it is estimated that the framing and erecting will cost about $12 per M ft. B. M., including iron. The cost of bolts and nuts will run about $1.50 per M ft. B. M. Roughly, then, this center will cost about $30 per M ft. B. M. in place. The center was designed by Mr. J. H. Milburn, Chief Draftsman, Office of the Chief Engineer, Baltimore & Ohio, R. R., Baltimore, Md.

Data on a Concrete Viaduct.—A reinforced concrete viaduct 2,800 ft. long has been recently built by John T. Wilson, of New York, for the Richmond & Chesapeake Bay Ry. Co., at Richmond, Va. It ranges in height from 18 ft. at each end to 70 ft. at the center. The reinforced concrete girders range in length from 23½ ft. to 67½ ft. c. to c. of bents. The bents are two-post bents, with legs 2 ft. square. The largest girder, having a length of 67½ ft., weighs 54 tons, its cross-section being 20 x 70 ins. In this viaduct there were 2,650 cu. yds. of concrete, and it required 172 ft. B. M. of timber for the forms and falsework per cubic yard of concrete. Kahn bars were used for reinforcing. The forms on the sides of the girders were removed at the end of 7 days, but the column forms and those supporting the girders were not removed for at least 30 days. While it is a single track viaduct, it is so designed that, by adding another series of posts and girders, it can be made

**Engineering-Contracting*, Nov. 14, 1906.

into a double track viaduct. One little trick in filling the column forms is worth bearing in mind. They were built U-shaped, the fourth side being left open, and built up as fast as the concrete was poured in from that side. This method facilitated working the concrete in around the reinforcing bars. Mr. J. H. McLure is Chief Engineer of the R. & C. B. Ry.

Cost of a Concrete Trestle and Three Concrete Girder Bridges With Abutments.*—The reinforced concrete trestle and the three bridges with concrete abutments that are referred to in this article were constructed near Easton, Pa., by Mr. M. P. McGrath, general contractor, of that place. The contractor or his engineer, Mr. J. F. Mooney, supervised the work so that while one man was employed nominally as a foreman and received $2.75 per day, he worked like

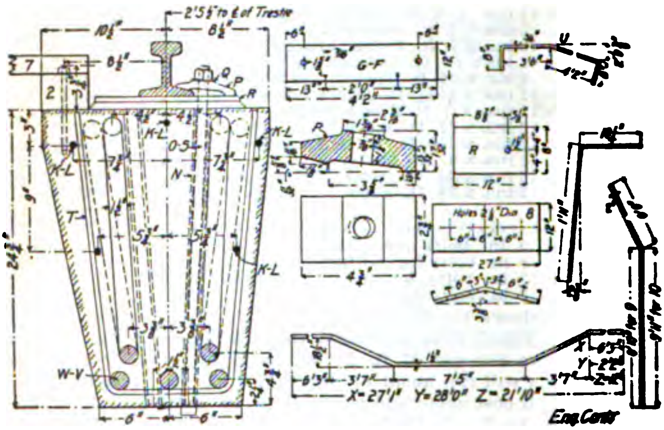


Fig. 28.—Details of Girder Rail Fastenings.

the other laborers; generally he was charged to placing or finishing. The costs given are actual costs except for the form lumber, which had been used before and the cost of which was approximated. The costs are given separately for each structure.

Coal Trestle.—The trestle was designed as a coal trestle and was constructed as shown by Figs. 28 and 29, except that the bents instead of being made solid, were built with a 4 x 8-ft. opening in each to permit the coal to flow more readily. There were 8 bents and two abutments and the trestle was 114 ft. long. It was designed to carry the rails directly on the girders without cross-ties, so that the girder reinforcement was made quite heavy, as is clearly shown by the drawings. It will also be seen that the rails had their bases partly embedded in the girders and were fastened by chairs. The chairs were of cast iron and were held by

*Engineering-Contracting, Feb. 5, 1908.

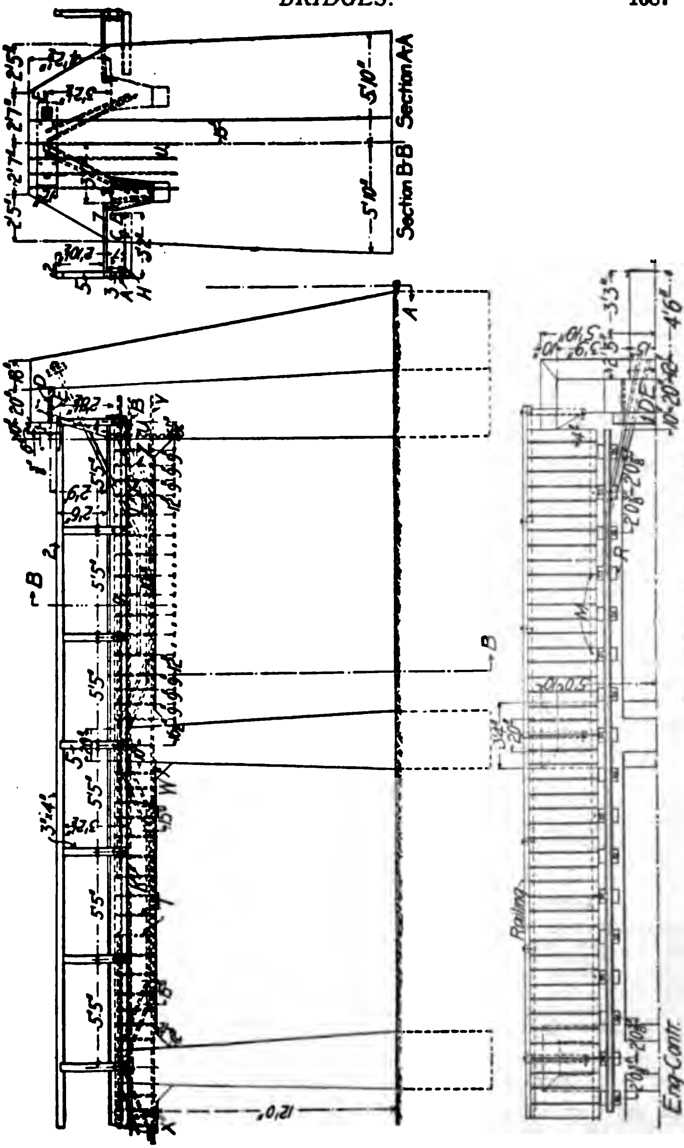


Fig. 29.—Concrete Trestle.

bolts extending down into the girder and secured under the lower reinforcement bar. The chairs were spaced 2 ft. apart, those of one rail being staggered with these of the other rail. This construction gave excellent results in operation and saved some 6 ins. in height over the ordinary cross-tie construction. The remaining structural details and dimensions of the trestle are clearly shown by Figs. 28 and 29.

The wages paid on this trestle and also on the bridge construction described later, were as follows:

Laborers, per 10-hour day	$1.50
Blacksmiths, per 10-hour day	2.00
Engineman, per 10-hour day	1.70
Carpenter, per 10-hour day	3.00
Foreman, per 10-hour day	2.75

The location of the trestle being almost flush against a railway embankment and it being necessary to locate the stock piles some 150 ft. from the mixer, made the cost of wheeling the materials high. The mixer was set up at the center point of the trestle and discharged into barrows which were hoisted by a pole and yard arm. The pole was provided with a yard and had a three-quarters swing. A rope passing over a pulley at the end of the yard arm was provided at one end with a three-line sling provided with a hook to attach to the wheel and two rings to slip over the handles. This rope hoisted the barrows to the top of the trestle by means of a horse hitched to the free end. The concrete used for the reinforced girders was a 1-2-4 mixture, the other parts of the trestle were made of 1-3-6 concrete in which were embedded stones ranging from the size of a man's head to the size of a half-barrel; these rubble stones were thrown into the forms in 1½-ft. layers. The total amount of concrete in this trestle was 116 cu. yds. and its cost was as follows:

Materials—	Per cu. yd.
1,069 bbls. cement, at $1.24	$1.325
0.631 tons sand, at 70 cts.	0.442
1.11 tons stone, at $1.25	1.387
131¼-lbs. steel, at 2 cts.	2.630
Lumber ($112.63 charged up)	0.971
Total materials	$6.755
Labor and Supplies—	
Making and erecting forms	$1.21
Handling sand	0.180
Handling stone	0.175
Mixing concrete	0.184
Placing concrete	0.300
Finishing concrete	0.103
Miscellaneous	0.246
Total labor	$2.398
Total labor and materials	$9.153

In the item miscellaneous were included blacksmith's work on reinforcement, handling cement, coal, oil, etc. As will be noted

the cost of reinforcement is distributed over the whole structure 116 cu. yds. of concrete; to be strictly accurate, the total 15,250 lbs. of reinforcing metal should be divided into the volume of concrete in the girders which, figured from the drawings, was approximately 24 cu. yds. This gives the great weight of 635 lbs. of reinforcement per cubic yard of concrete in the girders.

Bridge No. 1.—This structure had a clear span of 10½ ft. and consisted of two concrete girders, one under each rail, with ends embedded into concrete abutments with wing walls. The girders were 3 ft. deep, 2 ft. wide on top and 1½ ft. wide on the bottom and each was made of 1:2:4 concrete reinforced by five 1¼-in. round bars, three straight and two bent, with stirrups every 1½ ft. The abutments were made of 1:3:6 concrete. Conditions were favorable construction. As in the trestle rubble stones were incorporated in the abutment concrete; some cinders were also used and their cost is included in the cost of handling the stone. The bridge contained altogether 102 cu. yds. of concrete. The costs were as follows:

	Per cu. yd.
Materials—	
Cement	$1.264
Stone	1.688
Sand	0.444
Reinforcement	0.098
Lumber	0.383
Total materials	$3.877
Labor and Supplies—	
Forms	$0.479
Handling stone	0.175
Handling sand	0.077
Mixing concrete	0.100
Placing concrete	0.176
Finishing concrete	0.094
Miscellaneous	0.224
Total labor	$1.325
Total materials and labor	$5.202

The item miscellaneous includes hauling cement and water, work on reinforcement and coal. As in the trestle, the unit cost of reinforcement is got by dividing the total cost into the total yardage of concrete value as only the girders were reinforced.

Bridge No. II.—This bridge had a clear span of 16 ft. and was 13 ft. high, and like the bridge just described consisted of two concrete birders with ends embedded into concrete abutments. The girders were 22 ins. deep, 2 ft. wide on top and 1 ft. wide on the bottom. Each girder was reinforced with five 1⅜-in. round rods, three straight and two bent, without stirrups. The ties were fastened to the girders by embedded anchor bolts. The costs of materials changed somewhat from those given for the trestle and bridge No. 1. The cement cost $1.54 per barrel, and the stone (crushed on the ground) cost 73 cts. per ton. Rubble stones were incorporated in the abutment concrete as in the work previously described; this stone had all to be collected by men and teams and

this fact is reflected in the high unit cost of handling stone. The mixer was located so that its discharge chute overhung and discharged directly into the forms for one abutment. To reach the further abutment an ordinary coal chute was provided and the concrete chuted directly into place. The bridge contained 98 cu. yds. of concrete, which cost as follows:

Materials—	Per cu. yd.
Cement, at $1.54	$1.596
Stone	0.814
Sand	0.453
Reinforcement	0.176
Lumber	0.316
Total materials	$3,355
Labor and Supplies—	
Forms	$0.520
Handling stone	0.236
Handling sand	0.180
Mixing concrete	0.073
Placing concrete	0.157
Finishing concrete	0.092
Coal and water	0.041
Handling cement	0.078
Total labor	$1.377
Total materials and labor	$4.732

It will be noted that the cost of handling the stone for this bridge ran high because of the teaming referred to above. Reinforcement is charged into the total yardage as in the structures previously described.

Bridge No. III.—This bridge was built for the passage of farm wagons of 5 tons capacity. It had a clear span of 17 ft. and was 15 ft. wide and 17 ft. clear height. The floor consisted of four 12 x 6-in. girders carrying a 6-in. floor slab. The concrete was a 1 : 3 : 6 mixture throughout and was mixed by hand. The concrete was made with a broken tile aggregate obtained from a nearby tile works at the cost of handling only. This tile was very easily broken and left a rather poor finish to the concrete. There were 107 cu. yds. of concrete in the bridge and it cost as follows:

Materials—	Per cu. yd.
Cement	$1.594
Sand	0.459
Reinforcement	0.127
Lumber	0.280
Total materials	$2.460
Labor and Supplies—	
Forms	$0.41
Handling tile	0.692
Handling sand	0.112
Handling cement	0.105
Mixing concrete	0.413
Placing concrete	0.341
Total labor	$2.077
Total materials and labor	$4.537

In noting these costs the very heavy cost of handling the broken tile aggregate will be observed; on the other hand this aggregate cost nothing itself. The lumber charge is only that for new lumber, the old lumber that was re-used was not charged in. The cost of sand was 94 cts. per ton.

Cost of a Reinforced Concrete Trestle.—Mr. C. C. Mitchell gives the following data:

The trestle replaced an old wooden trestle 286 ft. long on a cable incline railway up Catskill Mountain, New York. The main structural features of the trestle and the slope of the ground on which it was built are indicated by Fig. 30. The work was done by contract after the cable incline had closed down on Oct. 17, 1908, for the season. Parts of the old timber structure were thus available for supporting forms and for such other purposes as the contractor required this kind of timber.

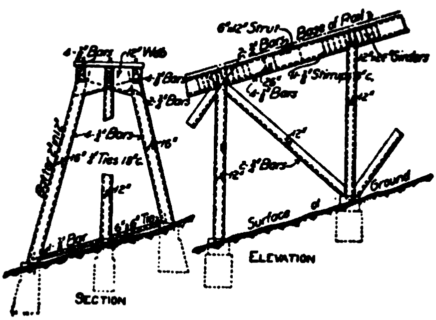


Fig. 30.—Concrete Trestle.

While waiting for the materials to arrive and the road to close down, excavation was begun on the footings, stone for the concrete was broken, a pipe line 1,000 ft. long was laid to a waterfall, a cement house and a shanty in which to fabricate the steel were built.

In excavating for the footings it developed that there were alternate strata of slate rock and earth, with boulders in about half of them, so that to get a good foundation on bedrock it was necessary to go from 4 to 10 ft. below the ground, the surface of which was so steep that it was very difficult to work on it. Slides and caving caused a much larger quantity of material to be handled than that represented by the holes excavated.

The excavations were walled up in pyramidal form on a batter of 2 ins. to the foot outward to within 2 ft. of the ground surface, there narrowing to a section 30x30 ins., on top of which a wooden box 30 ins. square and 24 ins. high was set up. Every bent had two such forms for the batter post footings, and every alternate

bent had in addition a third for the diagonal bracing struts to meet on. Then footings were concreted with a mixture of 1-3-6, the stone being broken by hand to 1½-in. size and the wooden top forms being shifted ahead as the work progressed, the stone-breaking, mixing board, etc., being likewise shifted ahead. Half of the lumber was stored at the lower end of the trestle and half at the middle; half of the sand at the middle and half at the upper end; half of the steel at the lower end and half at upper end, and all cement at the middle.

Five mixing boards were established along the trestle, and stone was broken successively at each as it was needed for the concrete. The water pipe, which ran alongside, was shortened as the work progressed. The sand and gravel were separated by screening and sent to the mixing boards through temporary chutes, the superstructure concrete being 1 part cement, 2 parts sand, 2 parts ¾-in. gravel and 2 parts ¾-in. stone.

Work was begun with a force of 10 men working 9 hours, of whom 1 was a foreman drawing $4 a day, 1 carpenter at $2.50, 1 steel bender at $2.25, and 7 laborers at $1.75 each. When the road closed down the force was doubled, 8 more laborers being added at $1.75 and 2 carpenters at $2 and $3.25, respectively, these latter working for a bonus.

Concreting the footings began on Oct. 18 and dismantling the old trestle at the same time, with some men fabricating steel, some building forms, some breaking stone and some excavating the upper footings.

The pulleys were first removed from under the cable, and the latter supported by 2x4-in. plank spiked to the old trestle bents, on which were also preserved the line and grade. The guard rails and track rails were next removed, then the cross ties and four inner stringers were unbolted and lowered by ropes to the ground and piled so as to form mixing boards. The remaining outside stringers were then shifted out to the ends of the bent caps, leaving a clear space in the center 8 ft. 6 ins. by 26 ins. deep. In some places the tops of these stringers were 2 ins. above grade and in other places 2 ins. below, otherwise they represented approximately the level for the new work and allowed a clearance of 3 ins. for the outside girder form of the new work. Next 2x6-in. spruce floor timbers for the girder forms were hung at 3-ft. intervals on a grade 27¼ ins. below by 2x4-in. battens spiked to the outside of the old stringers. The old bent caps were then gained out for each new girder to the grade of the floor timber, and a 1¼x12-in. by 16-ft. bottom board for each of the three new girder forms nailed in place. These girder forms were then built up to a depth of 26 ins. of 1¼x9-in. spruce matched boards, 1¼x4-in. pieces being used for battens every 36 ins. These sides were braced internally at 3-ft. intervals by tablets taken from the footing forms and placed like cross-partitions between the girder forms. The outer sides were braced by wedging against the 2x4-in. hangers and old supporting stringers, the tops of the latter being held from gaping outward by 1¼x4-in. strips nailed across the top over the floor timbers. The

three floor timbers at the center of each span were then further supported from below by struts composed of old ties and braces from the dismantled structure.

The forms for the batter posts and bracing struts were made up in trough form, leaving the outer and upper side open, then set in place on the foundation, and the tops sawed to fit the bottom of the girder forms. The webs were then built between their tops, uniting the whole with the girders. The post and strut forms were then properly braced and supported, the reinforcing steel put in place, a section of the fourth side put in place and the whole securely clamped together by ⅝x26-in. bolts passing tangent to two sides and drawing 2x4-in. yokes against the remaining two sides.

The reinforcement having been placed in the girders, the concrete was then poured in and carefully rammed and spaded, and the third side built up and clamped directly ahead of the concreting so as to permit the most careful placing of the latter without chance of displacing the reinforcement. These posts were concreted together up to the level of the girders for two bents usually. Owing to the 30° surface, the tops of the girders had to be boarded over continuously as the concreting progressed to keep it from running out, and a section of 1-in. pipe had to be left in place every 4 ft. in the outer girders through which to bolt the track to the new structure. When concreting stopped for the day bulkheads in the form of saddles were placed in the web at a bent, these bulkheads being removed the next day, allowing the concrete of each girder on the succeeding day to begin half way in the web of the preceding bent.

Each batter post was reinforced by a rack composed of ¾-in. rods wired to dowels in the footing or let into holes drilled in bed-rock, extending up through the girder above it nearly to the top surface and bound together every 18 ins. by a rectangular hoop of ¼-in. corrugated bar, previously bent to the right form and securely wired together. These racks were made up as needed, and when set in place inside the forms had about 1 in. of clearance around them and had to be constantly watched by the man ramming the concrete to keep them centered. Each strut brace had a ¾-in. rod within 1 in. of each of its two lower corners, wired to the footing dowels and passing up through the central girder nearly to the surface, and requiring great care in placing the concrete to maintain them in place.

Each girder had two ⅞-in. bars suspended from the cross-batters on top of the forms by wire, so that they lay 1½ ins. below the upper surface continuously, and two intermediate 8-ft. bars over each web for continuity. At 6-in. intervals eleven stirrups were hung on them at the bent webs and two more were hung near the center of span, so that they lay in V-shape normal to the axis of each girder and 1 in. distant from its bottom and sides. Four ⅞-in. bottom bars were then hung or laid in these stirrups, the length being 34 ft.; two were made to break joints at each bent. When these bars were all in place and securely wired, two ¾-in. bars were sprung into the cross-struts at the center of span and four more in

each of the webs and wired in place. Whereupon the girders were ready for concreting.

The congestion of steel at the webs made it difficult to place the concrete and properly ram it at and near the webs, and particularly to place and remove bulkheads and clean out the forms before going ahead with the concreting. It was also hard to place the concrete in the top of the bracing struts. The best results in placing the concrete were attained with a very wet mix, poured so that the water would flow up the forms ahead and be followed by a grout, which ran all around and between the reinforcement, leaving the stone and gravel to be rammed down into it at last.

The mixing was done by hand the gang being divided so that one batch was being separated while the other was being deposited. The sand and gravel were sent to the board by a chute, the stone broken at the edge of the board as used, and the cement carried to the board, each man taking a bag as he came to work and after lunch. Inclined runways of plank were shifted from bent to bent for the posts and others built from the mixing board to the top of structure and planks laid along the sides of the girder forms in such manner that the employes could return to the board without interfering with the loaded pails. Owing to the steepness of the ground and of the grade on the finished work, there was unusual danger of accidents and need of constant vigilance to prevent bad results from careless work, and this is the reason why only so many men were employed and in such a manner.

Because of the unexpected depth of thirteen of the footings, a ⅞-in. steel bar encased in 6 ins. of concrete was placed as a tie between the batter post feet wherever the latter did not reach directly to bedrock. This and 37 cu. yds. of extra concrete not indicated on the plans and a corresponding quantity of excavation not originally called for delayed the completion of the work, which was to have been finished on Dec. 1, so that it took until Dec. 12 to complete it. The weather was unusually favorable, being dry and warm until Nov. 3, from which time on there were light squalls of snow, succeeded by mild weather till Dec. 1, when it became so cold that the aggregates had to be heated. An old section of steel smokestack, 4 ft. in diameter and 12 ft. long, was filled with fire and sand and gravel piled over it, the water being heated in pails over a fire.

The 14 M. ft. of form lumber sufficed to complete about half the forms, and thereafter the forms first concreted, having been filled ten days, were stripped and the lumber used as the form work progressed. When the clamps were removed the post forms came off in four pieces in good shape to be set up again at once, but the girder and web forms had to be taken apart and rebuilt.

The top boards and tie strips were first pried off the top of the girders, the hangers and floor timber next removed, then the old stringers pried off and lowered with ropes, all the girder batters then knocked off, and the form boards taken off separately from both the outside and inside of girders, webs and struts. The bottom boards to the girders and diagonal strut braces were left in

place two weeks longer, with props under them, and then the old bent caps were sawed in two and the bent timber unbolted and dismembered, releasing the bottom boards, which were then removed, leaving the concrete completely stripped.

There was very little pointing necessary, except on the posts, which was done from a ladder, after which the exterior surfaces were given a wash of cement, alum and lye, rubbed in with a cement brick to waterproof the structure and remove board marks. The cable was blocked up on the concrete webs, the ties and guard rails bolted on, the pulleys rehung and track laid back in place by the Otis Railway Company, replacing track not coming under the contract.

The amount of work done under this contract was as follows: Excavation called for 87 cu. yds. earth, and extra excavation uncalled for 63 cu. yds. boulders, making a total of 150 cu. yds.; dismantling and piling 34 M. ft. yellow pine structure; 37 cu. yds. concreting (1-3-6) in extra footings; 125 cu. yds. concreting called for (1-2-4), reinforced; 13 tie rods for batter post feet; cleaning up and removal of debris; total cost, $4,332.14; contract price, $4,000; extras, $677.75; total, $4,677.75; profit on contract, $345.61.

Daily records were kept, showing kind of weather, temperature, amount of each kind of work done, with proportion of pay roll spent in doing it and the unit cost noted down for the immediate purpose of more economically planning the next day's work. A distribution statement showed the cost of both labor and material, charged up against each item of work performed during the week and the unit costs computed for each. A comparison was made between weekly average and daily rates, and the conditions prevailing on those days showing the most economic rates were then planned for the succeeding week's work.

Separate records were kept for the items applying to the general contract, the costs on extra work being kept apart. Finally all the costs were referred to the quantity of work done under them in the form of unit prices per cubic yard and the percentage which each represented to the whole.

The itemized cost of the work is given in Tables XXII, XXIII and XXIV.

TABLE XXII.—COST OF REINFORCED CONCRETE.

	Per cu. yd.
Materials—	
Cement	$2.31
Sand	1.73
Stone	2.00
Gravel	0.33
Water	0.35
Total materials	$6.72
Labor—	
Mixing and placing	$1.94
Pointing up concrete	0.37
Waterproofing concrete	0.60
Total labor	$2.91
Grand total concrete	$9.63

Forms—

Lumber, butts and nails	$4.75
Fabricating and erecting	3.58
Total forms	$8.33

Reinforcement—

Materials, bars, wire, etc.	$3.77
Fabricating	0.37
Placing	0.74
Total reinforcement	$4.88
Grand total for concrete work, 125 cu. yds.	$22.84

Miscellaneous—

Excavation, 87 cu. yds.	$0.56
Dismantling old trestle	1.00
Cleaning up at completion	0.40
General expenses, superintendence, etc.	4.45
Total miscellaneous	$6.41
Grand total	$29.25

TABLE XXIII.—COST OF EXTRA FOOTINGS.

	Per cu. yd.
Excavation, 63 yds. rock, at $2.89	$ 4.91
Aggregates: Cement, $1.94; sand, $0.97; stone, $1.01	3.92
Forms, material	1.20
Forms, labor	1.44
Concreting, labor	2.07
87 cu. yds. concrete	$13.50

TABLE XXIV.—THIRTEEN EXTRA TIE RODS.

	Per cu. yds.
Excavation	$ 6.01
Bending and placing steel rods	7.80
Form labor	8.35
Form material	8.30
Reinforcement (steel bars), ⅞ in.	5.10
Concreting labor	5.00
Aggregates: Cement, $2.70; sand, $1.35; stone, $3..	7.00
1½ yds. concrete	$47.50

These tie rods were of concrete, 6x6 ins., reinforced by ⅞-in. steel rods. The tie rods connected the feet of the batter posts, as shown in Fig. 30.

Standard Designs of Reinforced Concrete Culverts, C., B. & Q. Railway.*—Standard culvert designs for use on the Chicago, Burlington & Quincy Ry. have been worked out in reinforced concrete for box culverts ranging from 4x4 ft. to 10x12 ft. in size and for arch culverts from 4x4 ft. to 6x6 ft. in size. Up to and including in box culverts clear openings 7 ft. wide the pattern of structure shown by Fig. 31 is used; for clear openings of 8 ft., and over, the

***Engineering-Contracting,* Oct. 3, 1906.

TABLE XXV.

Box Culverts. Pattern Fig. 31.

Inside dimensions in ft.	Length of wing walls. Ft. Ins.	Cu. yds. concrete wing walls.	Cu. yds. conc., Lin. ft. Barrel.	Thickness side walls. Ins.	Thickness roof slab. Ins.	Thickness floor slab. Ins.
4 x 4....	5—10	7.4	0.75	12	12	12
4 x 5....	7— 6	9.2	0.83	12	12	12
4 x 6....	9— 2	11.6	0.9	12	12	12
5 x 4....	6— 1	9.0	0.91	12	14	14
5 x 5....	7— 9	11.3	0.99	12	14	14
5 x 6....	9— 6	13.9	1.06	12	14	14
6 x 5....	8— 0	13.5	1.18	12	16	16
6 x 6....	8— 0	16.5	1.25	12	16	16
6 x 8....	12— 9	18.3	1.60	15	16	16
7 x 5....	8— 4	15.65	1.39	12	18	18
7 x 7....	11— 5	24.9	1.72	15	18	18
7 x 8....	13— 0	29.13	1.82	15	18	18
Box Culverts. Pattern Fig. 32.						
8 x 6....	10— 0	31.0	1.89	15	20	20
8 x 8....	13— 4	39.7	2.08	15	20	20
8 x 10....	10— 5	5.71	2.51	18	20	20
10 x 10....	17— 0	62.3	3.07	18	24	24
10 x 12....	20— 4	76.0	3.3	18	24	24

pattern is modified as shown by Fig. 32. Figure 33 shows the pattern of arch structure used. The dimensions L and l in the box culvert designs are determined by the formulas,

$$L = \frac{10}{3} h + x + 3 \text{ ft.; and}$$

$$l = \frac{10}{3} h + x.$$

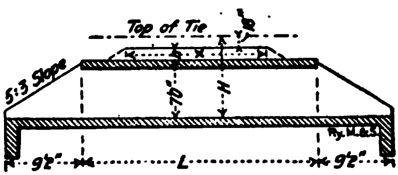


Fig. 31.

TABLE XXVI.

Inside dimensions in ft.	Length of wing walls. Ft. Ins.	Cu. yds. concrete in wing walls.	Lbs. of metal wing walls.	Cu. yds. conc. per lin. ft. barrel.	Lbs. of metal per lin. ft. barrel.
4 x 4...........	5— 3	6	236	0.5	54
5 x 5...........	6—11	10	401.7	0.71	76.7
6 x 6...........	8— 6	12	553.5	1.00	103.4

in which x = the width of roadbed at crown and h = the height of the fill above the culvert. In the arch culvert pattern the dimension L is determined by the formula,

$$L = \frac{10}{3} h + x + 4 \text{ ft.}$$

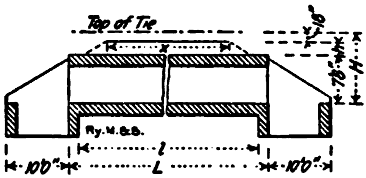


Fig. 32.

All other dimensions are determined by the cross-sectional size of the waterway. They are, for the various sizes adopted and with the exception of the reinforcement, shown in Table XXV.

Structural details of the 4x6-ft. culvert of pattern Fig. 31 are shown in Fig. 34, and Fig. 35 shows the similar details for the 10x12-ft. culvert of pattern Fig. 2. The same general details are employed for the culverts of intermediate and smaller dimensions.

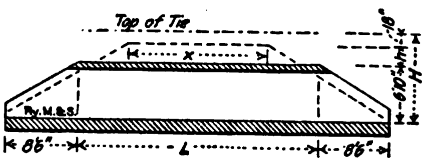


Fig. 33.

Turning now to the arch culvert pattern, Fig. 36 shows the structural details of the 6x6-ft. size. The main features of the other sizes of this pattern are shown by Table XXVI.

For culvert work the company uses a 1-3-6 concrete composed of 1.08 barrel of cement, 0.45 cu. yd. sand and 0.9 cu. yd. broken stone, or 1.25 barrels of cement and 1 cu. yd. of gravel.

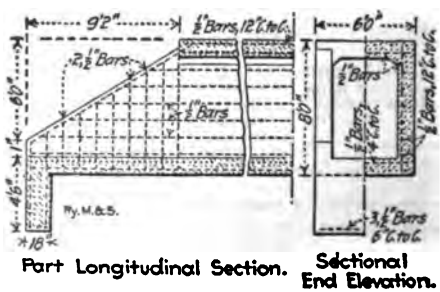
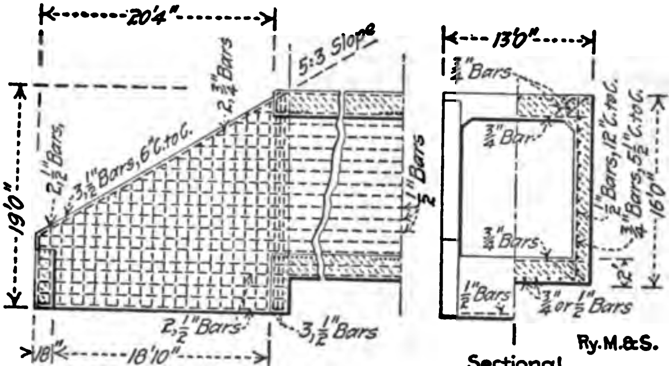


Fig. 34.

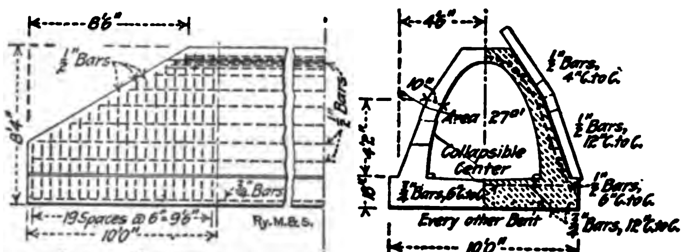
Cost of Concrete Culverts, References.—In *Engineering-Contracting*, Sept. 1, 1909, are given standard designs of box and arch culverts on the C., M. & St. P., together with quantities and costs. See Tyrrell's "Concrete Bridges and Culverts."

Cost of Reinforced Concrete Culvert.—The following data relative to the construction of a 4-ft. reinforced concrete box culvert in Missouri. The work was done under the supervision of P. S. Quinn, County Engineer. The culvert contained 28 cu. yds. of cement and 2,500 lbs. of steel bars. The concrete was a 1-4-8 mixture. Com-



Part Longitudinal Section. Sectional End Elevation.

Fig. 35.



Part Side Elevation. Sectional End Elevation.

Fig. 36.—Arch Culvert.

mon labor was paid 15 cts. per hour and carpenters 35 cts. per hour. The cost was as follows:

Material:	Total.	Per cu. yd. Concrete.
Cement, 23 bbls., at $1.50	$ 34.50	$1.23
Sand, 15 cu. yds., at $0.65	9.75	.35
Crushed limestone, 28 cu. yds., at $1.75	49.00	1.75
Steel, 2,500 lbs., at 2.3	57.50	2.05
Lumber, delivered	33.60	1.20
Total material	$184.35	$6.58

Labor:		
Carpenter, forms, 27 hrs	$ 9.45	$0.34
Helper, forms, 34 hrs	5.10	.18
Steel placing, 20 hrs	3.00	.11
Concrete, mix and place, 101 hrs	15.15	.54
Total labor	$ 32.70	$1.17
Grand total	$217.05	$7.75

The cost of placing the steel was $0.0012 per lb.

Cost of an Arch Culvert.—The cost of a concrete arch culvert, 26-ft. span, 62-ft. barrel (exclusive of excavation), with wing walls and parapet, built near Pittsburg in 1901, was as follows, the concrete being 1 to 8 and 1 to 10, hand mixed:

	Per cu. yd.
0.96 bbl. cement, at $1.60	$1.535
1.03 tons coarse gravel, at $0.19	0.195
0.40 ton fine gravel, at $0.21	0.085
0.32 ton sand, at $0.36	0.115
Tools, etc.	0.078
Lumber for forms and centers	0.430
Carpenter work on forms (23 cts. hr.)	0.280
Carpenter work on platforms and buildings	0.050
Preparing site and cleaning up	0.210
Changing trestle	0 085
Handling materials	0.037
Mixing and laying, av. 15½ cts. per hr	1.440
Total per cu. yd	$4.540

Wages per hour were: General foreman, 40 cts.; foreman, 25 cts.; carpenters, 22½ to 25 cts.; laborers, 15 cts. The finished structure contained 1,493 cu. yds., total cost being $7,243, including $463 for excavation. The work was done for a railway by company forces.

Cost of Six Arch Culverts and Six Bridge Abutments, N. C. & St. L. Railway.—Mr. H. M. Jones is authority for the following data: An 18-ft. full-centered arch culvert was built by contract on the N. C. & St. L. Ry., near Paris, Tenn. The culvert was built under a trestle 65 ft. high, before filling in the trestle. The railway company built a pile foundation to support a concrete foundation 2 ft. thick, and a concrete paving 20 ins. thick. The contractors then built the culvert, which has a barrel 140 ft. long. No expansion joints were provided, which was a mistake, for cracks have developed about 50 ft. apart. The contractors were given a large quantity of quarry spalls, which they crushed in part by hand, much of it being too large for the concrete. The stone was shipped in drop-bottom cars and dumped into bins built on the ground under the trestle. The sand was shipped in ordinary coal cars, and dumped or shoveled into bins. The mixing boards were placed on the surface of the ground, and wheelbarrow runways were built

up as the work progressed. The cost of the 1,900 cu. yds. of concrete in the culverts was as follows per cu. yd.:

1.01 bbls. Portland cement	$2.26
0.56 cu. yd. of sand, at 60 cts	.32
Loading and breaking stone	.25
Lumber, centers, cement house and hardware	.64
Hauling materials	.04
Mixing and placing concrete	1.17
Carpenter work	.19
Foreman (100 days at $2.50)	.13
Superintendent (100 days at $5.50)	.29
	$5.29

It will be seen that only 19 cu. yds. of concrete were placed per day with a gang that appears to have numbered about 21 laborers, who were negroes receiving about $1.10 per day. This was the first work of its kind that the contractors had done. It will be noticed that the cost of 42 cts. per cu. yd. for superintendence and foremanship was unnecessarily high.

The work in Tables XXVII and XXVIII was "company work" done by negro labor under company foremen.

TABLE XXVII.—COST OF SIX CONCRETE CULVERTS ON THE N. C. & ST. L. RY.

No. of culvert	1	2	3	4	5	6
Span of culvert	5 ft.	7.66 ft.	10. ft.	12 ft.	12 ft.	16 ft.
Cu. yds. of concrete	210	199	354	292	406	986
Ratio of cement to stone	1:5.5	1:6.5	1:5.8	1:5.8	1:6.1	1:6.5
Increase of concrete over stone	16.0%	9.9%	6.3%	12.3%	8.3%	5.3%
Bbls. cement per cu.yd.	1.02	0.90	1.06	1.01	1.00	1.09
Cu.yds. sand per cu.yd.	0.43	0.49	0.44	0.46	0.46	0.47
Cu.yds. stone per cu.yd.	0.86	0.90	0.95	0.89	0.94	0.94
Total days labor (incl. foremen and supt.)	702	607	784	726	768	1,994
Av. wages per day (incl. foremen and supt.)	$1.61	$1.33	$1.59	$1.19	$1.47	$1.46
Cost per cu. yd.:						
Cement	2.18	1.94	2.27	1.82	2.11	2.01
Sand	0.17	0.20	0.18	0.18	0.19	0.14
Stone	0.52	0.52	0.47	0.54	0.47	0.58
Lumber	0.88	0.43	0.48	0.43	0.31	0.57
Unload. materials	0.23	0.17	0.18	0.18	0.16	...
Building forms	1.07	0.33	0.62	0.47	0.72	0.41
Mixing and placing	1.59	1.74	1.69	1.35	1.23	1.26
Total per cu. yd.	$6.65	$5.30	$5.89	$4.97	$5.19	$4.97

Note:—All these arches were built under existing trestles, and in all cases, except No. 2, bins were built on the ground under the trestle and the materials were dumped from cars into the bins, loaded and delivered from the bins in wheelbarrows to the mixing boards, and from the mixing boards carried in wheelbarrows to place. Negro laborers were used in all cases, except No. 5, and

were paid 90 cts. a day and their board, which cost an additional 20 cts.; they worked under white foremen who received $2.50 to $3 a day and board. In culvert No. 5, white laborers, at $1.25 without board, were used. There were two carpenters at $2 a day and one foreman at $2.50 on this gang, making the average wage $1.47 each for all engaged. The men were all green hands, in consequence of which the labor on the forms in particular was excessively high. The high rate of daily wages on culverts Nos. 1 and 3 was due to the use of some carpenters along with the laborers in mixing concrete. The high cost of mixing concrete on culvert No. 2 was due to the rehandling of the materials, which were not dumped into bins but onto the concrete floor of the culvert and then wheeled out and stacked to one side. The cost of excavating and backfilling at the site of each culvert is not included in the table, but it ranged from 70 cts. to $2 per cu. yd. of concrete.

TABLE XXVIII.—COST OF CONCRETE ABUTMENT, RETAINING WALLS AND FOUNDATIONS.

No. of structure	7	8	9	10	11	12
Cu. yds. of concrete	310	99	282	78	71	72
Ratio of cement to stone	1:5.7	1:6.3	1:5.9	1:6.6	1:5.7	...
Increase of concrete over stone	6.2%	10.0%	12.8%	4.0%	10.9%	...
Bbls. cement per cu.yd.	1.09	0.95	0.99	0.96	1.03	1.39
Cy.yds. sand per cu.yd.	0.47	0.45	0.44	0.51	0.45	0.56
Cu.yds. stone per cu.yd.	0.94	0.91	0.90	0.96	0.90	1.09
Total days labor (incl. foremen)	573	226	599	128	131	224
Av. wages per day (incl. foremen)	$1.43	$1.88	$1.46	$1.69	$2.05	$1.55
Cost per cu. yd.:						
Cement	$2.32	$1.66	$1.98	$2.07	$2.19	$2.95
Sand	0.19	0.18	0.18	0.21	0.18	0.17
Stone	0.52	0.18	0.22	0.48	0.18	0.65
Lumber	0.56	0.09	0.26	0.26	0.51	0.34
Building forms	0.35	0.40	1.09	...	...	...
Mixing and placing	1.94	3.38	1.36	2.21	1.74	2.59
Totals	$5.88	$5.91	$5.09	$5.23	$4.80	$6.70

Note:—Structure No. 7 consists of two abutments to carry a 24-ft. span bridge made of I-beams. Bins to hold stone and sand were built on the railway embankment. At the head of the bin a part of the bank was dug away under the track, and long stringers put in to carry the track. The rock was dumped from the car into this opening and shoveled into the bin. The forms for the concrete were, of course, simpler than for the arches in Table XXVII; hence the labor on them cost less.

Structure No. 8 consists of concrete side walls to support a cedar cover, forming a culvert. Slag was used instead of crushed stone in this structure as well as in Nos. 9 and 11.

Structure No. 9 is a retaining wall. There was much handling of materials due to lack of room for storage near the work. Old material was used for the forms.

Structures Nos. 10 and 12 are foundations for track scales. It is not clear why the labor cost of this work was so very high.

Cost of Reinforced Concrete Railroad Culvert in Montana.—In *Engineering-Contracting*, July 1, 1908, Mr. Henry A. Young gave the following: The following cost data were obtained from the Huntley Project of the U. S. Reclamation Service, located at Huntley, Mont., and show in detail the construction costs for a culvert carrying the canal under the Burlington & Missouri River R. R. The culvert was known as the "1st Culvert under the B. & M. R. Ry.," and was of a type similar to the designs of W. W. Colpitts, Assistant Chief Engineer, Kansas City, Mexico & Orient Ry., having two barrels, each barrel being 6 ft. 6½ ins. x 7 ft. 6 ins. and 24 ft. long. The roof was flat, the walls provided with fillets at top and bottom, and the entrance and outlet consisted of warped walls 20 ft. long opening into a canal section 20 ft. wide at bottom and having side slopes of 1½ on 1. The entire structure was of concrete, heavily reinforced with Johnson high carbon corrugated bars, 1 in. and ¾ in. in diameter.

The work was not done cheaply, and the figures are given to show the outside cost for this class of structure, built under the most unfavorable conditions. This was the first structure built on the project, the entire gang, mechanics and laborers, was green, and the work was done in November and December, 1905, the weather being very cold. An 8-hour day was worked. After the experience on this culvert the same gang did work for about two-thirds of the costs recorded here. The forms for the warped walls in this case gave considerable trouble.

A Municipal Engineering and Contracting Company's 1-3 cu. yd. cubical mixer was set about 50 ft. in front of the culvert. A gasoline pump took water from a creek 60 ft. away and delivered it to a tank near the mixer. The delivery pipe froze often and delayed the work. The mixer was fed by and the concrete was carried by wheelbarrows.

The concrete was put in wet and spaded. A 1-in. course of 1-2 mortar was placed on floor, copings, etc., and troweled. Chamfer strips were used on all sharp angles and fillets in culvert.

The earth was a sandy clay and was removed with slips, though considerable hand work was done in shaping up.

Sand and gravel were obtained from a pit about 1½ miles from the culvert. The wheel at pit was about 40 ft., the material being

screened into a bin. The haul was down hill. Cost delivered is recorded in table.

Cement, steel and other materials were hauled from a station about 1 mile from culvert.

The costs recorded do not include backfill, which was paid for under puddling, the trimming and finishing of exposed concrete walls, nor the construction and removal of a temporary railroad bridge. The work was done by contract, but actual costs are given whether borne by the contractor or the government, and no allowance is made for depreciation or for engineering expenses. The quantities consisted of 338 cu. yds. of excavation and 162 cu yds. of reinforced concrete, the latter mixed in the proportion of 1-2¼-5, the maximum size gravel being 2 ins.

Lumber was taken at its full cost, which is not absolutely correct, as it was later used over again on other structures. Probably one-third of the lumber charge would have been more nearly correct.

Excavation:	Days.	Rate.	Total.
Superintendent	3½	$166.67	$ 19.44
Foreman	5	50.00	8.33
Laborers (loading slips and excavat'g)	31⅜	2.00	62.75
2-horse teams, slip and drivers	8¾	3.60	31.50
Excavating 338 cu. yds. (sandy clay, dry), at $0.361			$122.02
Forms (162 cu. yds.):			
Lumber, 10,550 ft. B. M.		$20.25	$213.64
Nails, 2 kegs		3.20	6.40
Total material for forms			$220.04
Carpenters	90⅔	$3.00	$272.00
Laborers	45⅛	2.00	90.25
Hauling (teams)	3⅛	3.60	11.25
Total labor, building and removing forms			$373.50
Materials:			
Cement, 225 bbls		$1.76	$396.00
Cement, 12¾ bbls		1.86	23.71
Sand, 71 cu. yds		1.58	112.18
Gravel, 134 cu. yds		1.58	211.72
Coal, 3½ tons		3.25	11.37
Gasoline, 25 gals		.35	8.75
Total materials			$763.73
Labor:			
Laborers	141¼	$2.00	$282.50
Foreman	18⅛	2.40	43.50
Cement worker	7 13-16	4.00	31.25
Cement helper	2¾	1.60	4.40
Teams (hauling cement and water)	2⅞	3.60	10.35
Total labor, mixing and placing			$372.00
Reinforcement:			
Hauling (labor and teams)			$16.25

Bending bars:			
Laborers	11⅛	$ 2.00	$22.25
Blacksmith	11⅛	2.40	26.70
Superintendent (working plans)	1	166.67	5.56
Foreman	1	50.00	1.67
Blacksmith coal, 3 sacks		1.00	3.00
Total labor, bending			$59.18
Placing bars:			
Laborers	34	$2.00	$68.00
Blacksmith	1⅝	2.40	3.90
Total labor, placing bars			$71.90
Steel bars, 25,585 lbs		$0.027	$690.79
Installing and removing plant:			
Laborers	4½	$2.00	$9.00
Teams	5	3.20	16.00
Total			$25.00
Superintendence:			
Superintendent	32	$166.67	$177.78
Foreman	31	50.00	51.67
Total			$229.45

Summary of Concrete.

	Per Cu. Yd.
Material for forms	$1.358
Labor on forms	2.306
Materials for concrete	4.714
Labor, mixing and placing	2,296
Steel for reinforcement	4.264
Hauling steel	0.100
Labor, bending steel	0.365
Labor, placing steel	0.444
Installing and removing plant	0.154
Superintendence and foreman	1.416
Total cost of concrete	$17.417

The cost of the steel reinforcement, in terms of the pound of steel as the unit, cost as follows:

	Per lb. Cts.
Steel bars	2.70
Hauling	0.06
Bending	0.23
Placing	0.28
Total	3.27

Cost of a Stone Arch Culvert.*—This culvert was erected by contract for the Chicago & West Michigan Ry., in 1891-1892. The culvert was built some distance from the original channel, and a new channel was cut through to the arch after it was completed. The excavation was carried 4½ ft. below water level. A cofferdam was built of 2x8 in. x 8 in.x 7 ft. sheet piling, which was driven by hand. Pumping was done with a centrifugal pump, the power being furnished by a traction engine. The pump was run only one-quarter of the time, for the water did not come in rapidly. All excavation was done by men with shovels and wheelbarrows.

**Engineering-Contracting,* Jan., 1906.

The stone for the culvert was a sandstone scabbled at the quarry, and but little work had to be done on the top and bottom beds. Joints and beds were laid for 10 ins. back of the face with Portland cement, and the rest was laid with Louisville natural cement. Two derricks were used alternately and were run with steam power.

Work on the excavation commenced Oct. 5, 1891; a hand pump being used from Oct. 21 to 29; and a steam pump being used from Oct. 29 to Nov. 26, and from Jan. 29 to Feb. 3, 1892. The first stone was laid Nov. 7; the centers were raised Dec. 4; the keystone was finished Jan. 20; the last stone was laid Jan. 25; and the centers were struck Jan. 29. The plant was moved away Feb. 6. After Dec. 7, salt was used in hot water for mixing the mortar.

The following was the cost to the railway and to the contractor:

Price Paid to Contractor.

1,041 cu. yds. dry excavation, at 25 cts.	$ 260.25
617 cu. yds. wet excavation, at 75 cts.	462.75
594 cu. yds. excavation for channel, at 25 cts.	148.50
16,740 ft. B. M. beech timber in foundation, at $30	502.20
20,286 ft. B. M. 3-in. pine plank, at $22	446.29
495.9 cu. yds. first-class masonry cut and placed (including cement and sand), at $7.50	3,719.25
504 ft. B. M. sheet piling protection for ends of arch, at $14	7.05
140 hours' work driving sheet piling and riprapping at end of arch, at $0.15	21.00
20 hours, engine and engineman, ditto, at $0.40	8.00
10% on $29 labor	2.90
Total	$5,578.19

Cost to C. & W. M. Ry.

481.9 cu. yds. sandstone, at $6.82	$3,284.95
Contractor's payment as above	5,578.19
Total	$8,863.14

The above is the cost of sandstone f. o. b. La Porte. There were 57 carloads of stone, of 272.4 cu. ft. of stone per car, weighing 157 lbs. per cu. ft.

Actual Cost of Material and Labor.

Materials:

4,000 ft. B. M. 2 x 8 in x 7 ft. T. & G. sheet piling, at $14	$ 56.00
16,740 ft. B. M. beech timber, 12 in. thick, hewed, at $10	167.40
20,286 ft. B. M. 3-in. pine plank in foundation, at $14	283.92
1,800 ft. B. M. rough hemlock, 3 x 12 ins., in centers, at $10	18.00
1,500 ft. B. M. pine (dressed 1 side), 3 x 12 ins., in centers, at $14	21.00
1,600 ft. B. M. pine (dressed 1 side,) 2 x 4 ins., lagging, at $14	22.40
Old timber in bents under center	10.00
Posts and walling for sheet piling (round timber)	10.00
160 bolts in centers, ⅝ x 12 ins., 200 lbs., at 4 cts.	8.00
3,000 boat spikes, ⅜ x 7 ins., 1,000 lbs., at 2½ cts.	25.00
65 cu. yds. sand, at 75 cts.	48.75
95 bbls. Louisville cement, at $1	95.00
2 bbls. salt, at $1	2.00
70 cords 16-in. wood, fuel for engines, at $1.25	87.50
Total for materials	$931.97

Labor:

34	days foreman of laborers excavating, at $2	$ 68.00
76	days foreman of masons, at $2.50	190.00
73½	days engineman, at $2	147.00
287½	days stone cutters, at $3	1,162.50
10	days carpenters, at $2	20.00
622	days laborers, at $1.50	933.00
23	days team, at $3	69.00
	Total for labor	$2,589.50

General expense:

85 days timekeeper, at $1	$ 85.00
Repairs to stonecuters' tools	65.00
30 days traction engine and engineman, at $3	90.00
60 days rent on engine when idle, at $1.50	90.00
10% value of $2,000 plant	200.00
Total general expense	$530.00

Summary:

Total materials	$ 931.97
Total labor	2,589.50
Total general expense	530.00
Grand total	$4,051.47
Profit to contractor	1,526.72
Contract cost to railway	$5,578.19

Itemized Cost.

Dry excavation	$ 185.00 or 17.8 cts. per cu. yd.
Wet excavation and driving sheet piles	202.50 or 32.8 cts. per cu. yd.
Putting 16,740 ft. B. M. beech timber in place	40.00 or $2.38 per M.
Putting 20,286 ft. B. M. plank in place	45.00 or $2.22 per M.
Building and erecting centers	31.00 or $6.20 per M.
Unloading stone from cars	37.50 or $0.07¾ per cu. yd.
Cutting stone, 496 cu. yds.	1,282.25 or $2.59 per cu. yd.
Setting stone, 496 cu. yds.	483.50 or $0.97 per cu .yd.
Handling and erecting plant	150.00
Excavating channel	110.25 or 18.6 cts. per cu. yd.
Sheet piling and riprap	22.50

The foregoing record, while very complete, would be more satisfactory if it contained a detailed statement of the organization of the forces. For example, how many masons, how many mortar mixers, how many masons' helpers on the wall, how many tag-men slewing the derrick boom, etc., were there to each derrick? Then, again, a sketch of the plant layout, and a rough drawing showing the general design of the culvert would be a valuable addition.

While the day of cut-stone arch culverts is rapidly passing away, such culverts are still specified. Concrete is cheaper than cut-stone masonry, but it is not always cheaper than rubble. We may expect to see a greater use of rubble masonry when engineers come to have a more detailed knowledge of costs.

If the contractor is left to himself, he can often build rubble masonry at less cost than concrete. Engineers, however, often draw

indefinite or very exacting specifications for rubble, and get, as a result, prices that are higher than for concrete. Rubble is particularly cheap where the job is small and where broken stone can not be hauled in except at great expense.

In considering the cost of excavation above given, it should be remembered that conditions were such that the material could be moved in wheelbarrows. If a derrick had to be used, the cost would have been much more.

Cost of Reinforced Concrete Subways.*—In 1903 the Lake Shore & Michigan Southern Ry. constructed, with its own workmen, three reinforced concrete subways at Elkhart, Ind., to carry a highway under its tracks and thus do away with grade crossings.

The three subways had a length of barrel 40 ft., 60 ft., and 160 ft. long, respectively, exclusive of wing walls. They were built as arches of 30-ft. clear span and 13-ft. headway, with a thickness of 28 ins. at the crown.

Steel bars of the Johnson corrugated pattern, made by the St. Louis Expanded Metal Fire Proofing Co., were used for the reinforcement, circumferential bars, spaced 6 ins. center to center, being laid 2½ ins. from the extrados and intrados; across these were transverse rods, 2 ft. center to center, running the full length of the barrel. The steel rods were put in according to the Monier plan.

The concrete used in the construction was mixed generally in the proportions of 1 part cement to 3 parts gravel and 6 parts sand. The gravel was dug from the foundations and was about one-half sand and one-half gravel. The latter component varied somewhat and the proportion of cement was varied accordingly, more cement being used when the proportion of sand in the gravel increased. The concrete was machine mixed and a wet mixture used.

The three subways contained 4,833 cu. yds. of concrete, the cost per cubic yard of concrete being as follows:

	Total.	Per cu. yd.
Temporary buildings, trestles, etc.	$ 752	$0.15
Machinery, pipe, etc.	416	.08
Sheet piling and boxing	1,006	.21
Excavating and pumping	1,620	.33
Arch Centers and Boxing—		
46 M. ft. at $25	1,150	.24
10 M. ft. at $13	130	.03
Labor in centers (carpenters at 22½ cts.; laborers, 15 cts.)	2,250	.46
Concrete Masonry—		
Cement at $1.83	8,861	1.83
Stone	1,788	.37
Sand and gravel (obtained from foundation)	240	.05
Drain tile	103	.02
Labor	8,091	1.68
Steel reinforcing rods, at 2½ cts. per lb.	3,028	.63
Engineering, watchmen, etc.	508	.11
Total	$29,944	$6.19

*Engineering-Contracting, Oct. 17, 1906.

We are indebted to Mr. Samuel Rockwell, Chief Engineer Lake Shore & Michigan Southern Ry., for the above data.

Cost of a Dry Masonry Box Culvert.—Dry masonry box culverts have been used extensively in railroad construction, and their use will no doubt continue, especially where the haul of cement is long, as in new construction in mountainous sections of the country, also where the amount of work to be done does not justify the installation of a rock crusher. Records of cost of such work are, consequently, of value.

Among the many classes of culverts constructed, none is more lasting than a well-built dry masonry culvert. See Fig. 37. Where large stones with well defined faces can be secured, such as from rock cuttings on railroad work, these culverts can be built strong and with a very neat finish. Care should always be taken to secure good, firm bottom, and the foundation course should be placed well below the bed of the stream, and thus prevent undermining of the walls. The paving should not extend under the walls of the cul-

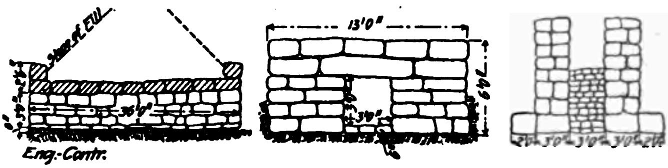


Fig. 37.—Masonry Culvert.

vert, for should a part of the paving become misplaced, the small paving stones will be washed from under the walls, causing the latter to cave in and ruin the culvert. The lower course of stones should be as large as can be conveniently handled, so that heavy floods, that may injure the pavement will not misplace the wall stones.

We give here the cost of a 3x3-ft. dry masonry culvert, 36 ft. long:

Excavation for foundation	20 cu. yds.
Laborers, 22 hrs. at 20 cts.	$ 4.40

This gives a cost of 22 cts. per cu. yd. for excavation.

Masonry—

Mason, 60 hrs. at 40 cts.	$24.00
Laborers, 130 hrs. at 20 cts.	26.00
Team and teamster, 40 hrs. at 45 cts.	18.00
Derrick, 40 hrs. at 15 cts.	6.00
Total	$74.00

The culvert contained 50 cu. yds. at a cost of $74, or $1.48 per cu. yd. The stone for this culvert was taken out of a rock dump 20 ft. away. Some of the large covers had to be handled 400 ft. The derrick used was the ordinary three-leg derrick, legs 20 ft. long,

and the derrick boom was 24 ft. long, one set reaching the full length of culvert, the derrick cable being operated by horse power, pulling through block and tackle.

Cost of Concrete Culvert Pipe.*—The methods and cost of molding 4-ft. concrete culvert pipe given in the following paragraphs have been obtained from Mr. O. P. Chamberlain, Chief Engineer, Chicago & Illinois Western R. R.

During the summer of 1906 Mr. Chamberlain built a number of culverts, using a 4-ft. long concrete pipe molded in the form of

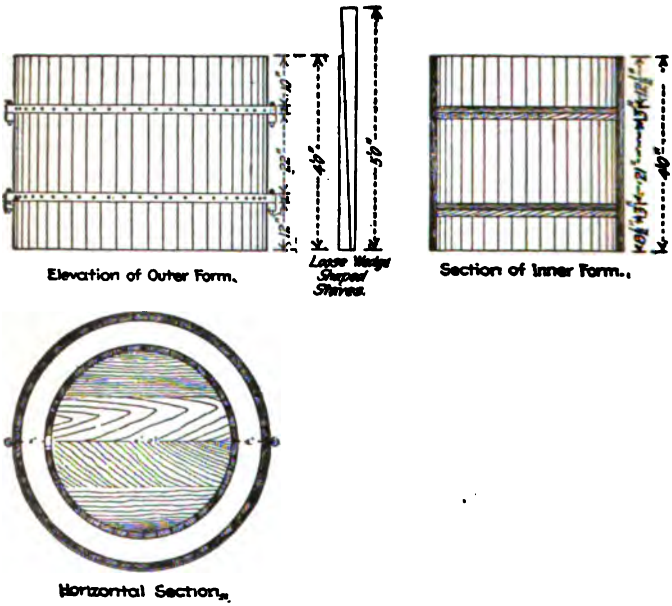


Fig. 38.—Forms for Culvert Pipe.

hollow cylinders with square ends. They were molded with an interior diameter of 4 ft. and with 6-in. shells, giving an outside diameter of 5 ft. These pipes were laid end to end in trenches whose bottoms were cut as closely to a circle of 5 ft. diameter as could be done with pick and shovel and were covered with earth thoroughly tamped around the tops and sides. The pipes were used in low embankments, where their tops are but 18 ins. below the bottom of the ties, and thus far they have given satisfactory service under heavy freight traffic.

*Engineering-Contracting, Feb. 13, 1907.

Figure 38 in a reproduction of the working drawings from which the forms used in the construction of these pipes were built. Both forms are of wood, of ordinanry wooden tank construction. The inner form has one wedge shaped loose stave which is withdrawn after the concrete has set for about 20 hours, thus collapsing the inner form and allowing it to be removed. The outer form is built in two pieces with 2 x ⅝-in. semicircular iron hoops on the outside, the hoops having loops at the ends. The staves are fastened to the hoops by wood screws 1¾ ins. long driven from the outside of the hoop. When the two sides of the outer form are in position, the loops on one side come into position just above the loops on the other side, and four ¾-in. steel pins are inserted in the loops to hold the two sides together while the form is being filled with concrete and while the concrete is setting. After the inner form has been removed, the two pins in the same vertical line are removed and the form opened horizontally on the hinges formed by the loops and pins on the opposite side. The inner and outer forms are then ready to be set up for building another pipe.

The concrete used in manufacturing these pipes was composed of American Portland cement, limestone screenings and crushed limestone that has passed through a ¾-in. diameter screen after everything that would pass through a ½-in. diameter screen had been removed. The concrete was mixed in the proportions of one part cement to three and one-half parts each of screenings and crushed stone. All work except the building of the forms was performed by common laborers. In his experimental work Mr. Chamberlain used two laborers, one of whom set the forms, and filled them and the other of whom mixed the concrete. The pipes were left in the forms till the morning of the day after molding. The two laborers removed the forms filled the day before, the first thing in the morning, and proceeded to refill them. The average time the concrete was allowed to set before the forms were removed was 16 hours. Mr. Chamberlain believes that with three men and six forms the whole six forms could be removed and refilled daily. Based on the use of only two forms with two laborers removing and refilling them each day, and on the assumption that a single set of forms costing $40 can be used only 50 times before being replaced, Mr. Chamberlain estimates the cost of molding 4-ft. pipes as follows:

2 per cent of $40 for forms	$0.80
1.1 cu. yds. stone and screenings at $1.85	2.04
0.8 bbls. cement at $2.10	1.68
10 hours' labor at 28 cts.	2.80
Total per pipe	$7.32

This gives a cost of $1.83 per lineal foot of pipe or practically $7 per cu. yd. of concrete. The pipe actually molded cost $2.50 per lin. ft., or $9.62 per cu. yd. of concrete, owing to the small scale on which the work was carried on—the laborers were not kept steadily at work.

The pipes were built under a derrick and loaded by means of the derrick upon flat cars for transportation. At the culvert site they were unloaded and put in by an ordinary section gang with no appliances other than skids to remove the pipes from the cars. As each four-foot section of this pipe weighs about two tons, it was not deemed expedient to build sections of a greater length than four feet, to be unloaded and placed by hand. On a trunk line, however, where a derrick car is available for unloading and placing the pipes, there is no reason why they should not be built in six or eight-foot sections.

Basing his estimates on the above price of $7 per cu. yd. for concrete, Mr. Chamberlain has computed the accompanying table of comparative weights and costs of cast-iron and concrete pipes of various diameters. The cost of cast-iron pipe per pound is assumed to be 1⅝ cts.

TABLE XXIX.—SHOWING RELATIVE THICKNESS, WEIGHTS, AND COST OF "STANDARD" CAST-IRON PIPE AND CONCRETE.

Size and kind of pipe.	Thickness in ins.	Weight lbs. per lin. ft.	Cost per lin. ft.
12-in. cast-iron	0 33/64	75	$1.22
12-in. concrete	2	88	0.16
18-in. cast-iron	0 47/64	167	2.72
18-in. concrete	3	220	0.36
24-in. cast-iron	1	250	4.07
24-in. concrete	4¼	420	0.68
30-in. cast-iron	1 1/16	334	5.43
30-in. concrete	4½	602	0.88
36-in. cast-iron	1⅛	450	7.32
36-in. concrete	4¾	676	1.10
42-in. cast-iron	1⅜	600	9.75
42-in. concrete	5¾	960	1.55
48-in. cast-iron	1 7/16	725	11.78
48-in. concrete	6	1131	1.83

In Table XXIX. the thickness for concrete pipes of various diameters has been taken as approximately proportional to the thickness of "Standard" cast-iron pipes of the same diameter, the 4-ft. diameter pipes being used as a basis for calculation.

The first cost of concrete pipes at the place of manufacture would, according to the above table, be less than one-sixth of the cost of cast-iron pipes. The cost of transportation and of installing the pipes would, on account of the greater weight and greater number of pieces, probably be very nearly double that for cast-iron pipes.

On account of the lack of reliable data regarding this cost, Mr. Chamberlain is unable to give a fair comparative estimate of the cost of the two styles of culverts in place. However, since transportation and installation of iron pipes is but a small proportion of the cost of the completed culverts, it is evident that cost of a concrete pipe culvert in place would be but a small fraction of the cost of a cast-iron pipe culvert of the same diameter, provided the pipes were hauled only moderate distances.

Cost of Placing Cast Iron Pipe Culverts.—Mr. John C. Sesser, Engineer of Construction, C., B. & Q. Ry., gives the following data on the cost of unloading, hauling and placing cast iron pipe. In 1905 that railroad on its extension from Centralia, Ill., to Herrin, used for its culverts ordinary cast iron pipes up to a size of 48 ins. in diameter. The contract for handling the pipe was let to a contractor at 75 cts. per ton per mile for the unloading and hauling and $2.00 per ton for placing. A careful record was kept of all labor employed in handling this pipe, and from these data the following results were obtained:

Number of tons of pipe handled	591
Cost per ton for unloading from flat and gondola cars	$0.33
Average miles hauled	3.82
Cost of hauling per ton mile	0.44
Cost per ton mile for unloading and hauling (av. haul 3.82 miles	0.53
Cost per ton for laying	0.55
Cost per ton in place	2.39

The greatest distance the pipe was hauled was about 10 miles. From the data obtained it was deduced that: The cost per ton for unloading the pipe is the same regardless of size; that the cost of laying pipe per ton, for pipe under 30 ins. in diameter, is about 30 per cent more than for pipe over 30 ins. in diameter. As a matter of fact it costs about twice as much per ton to lay 18-in. pipe as it does to lay 48-in. pipe.

Cost of Cast Iron Pipe Culverts.—The labor cost of pipe culverts depends almost entirely upon the amount of excavation involved. If an existing railway embankment must be cut through, obviously the labor cost will be far higher than if the pipe is laid under a trestle that is to be filled in.

For the weight of cast iron pipe, see the section on Waterworks. Also consult that section for the labor cost of handling pipe.

Mr. A. W. Merrick gives the following data of work done in 1898 on the Chicago & Northwestern. Where the embankment is more than 12 ft. high, an open trench is excavated from the toe of each slope to a point 6 ft. from the center of the track. This leaves a core 12 ft. wide under the track, through which a tunnel is dug. It is often well to insert two old stringers under the rails to keep the weight off the earth over the tunnel during construction. The trench is sheeted with vertical planks and braced. The roof of the tunnel is supported by 4-in. plank which rest on 3 x 12-in. posts whose feet stand on 3 x 12-in. mudsills running lengthwise of the tunnel. Wedges are placed between the posts and the mudsills. For a 24-in. pipe the tunnel is made 4 x 4 ft. Two planks are laid side by side in the bottom of the trench for dollies to run on, and each length of pipe is drawn in on a dolly at each end.

The cost of a 24-in. pipe culvert, 48 ft. long, in a bank 13 ft. high, was:

	Per lin. ft.
Cast-iron pipe, 250 lbs., at $16 per ton	$2.00
Labor	1.08
Total	$3.08

The cost of a 24-in. pipe culvert, 84 ft. long, in a bank 24 ft. high, was:

	Per lin. ft.
280 lbs. cast-iron pipe, at $16 per ton	$2.00
Labor	1.73
Plank and nails	0.07
Total	$3.80
End walls, $69	0.80
Total	$4.60

The detailed cost of these two end walls was:

2 cords stone, at $3.25	$ 6.50
18 footing stone, at $0.80	14.40
20 coping stone, at $0.50	10.00
6 sacks cement	1.37
Mason labor	36.85
Total	$69.12

Mr. A. S. Markley gives the following costs in 1898 of work on the Chicago & Eastern Illinois, laborers receiving $1.50 per day, and foremen $2.50.

Size of pipe.	Condition.	Labor. Per ton.	Labor. Per ft.
48-in.	Opening provided	$1.25	$0.36
36-in.	Tunneling 15 ft. bank	4.96	0.88
36-in.	Trench, 8 ft. bank	3.18	0.63
18-in.	Trench, 4½ ft. bank (7 tracks)	1.06	0.16
16-in.	Trench, 4½ ft. bank	1.06	0.16

Mr. W. A. Rogers gives the following costs in 1898 on the Chicago, Milwaukee & St. Paul. It is not stated just what the conditions were, but many of the pipes were drawn through existing timber culverts and earth tamped around them. Most of the pipes were cast in 6 ft. lengths, and the price was $14.50 per ton.

Diameter.	Material.	Labor.	Total.	Cost of each masonry end.
20 ins.	1.00	1.08	$2.08	$ 43
24 ins.	1.20	1.38	2.58	53
30 ins.	1.72	1.42	3.14	66
36 ins.	2.45	1.64	4.09	78
42 ins.	3.35	1.98	5.33	90
48 ins.	4.30	2.36	6.66	100

No pipe smaller than 20 ins. is used, for this is the limiting size that a man can crawl through when it is necessary to clean a pipe out. Larger sizes than 48 ins. have caused trouble by breaking. Pipes were put in by the track department.

Mr. Geo. J. Bishop gives the following cost in 1898 of work on the Chicago, Rock Island & Pacific. The pipes were all laid under trestles that were to be filled in. Hence the labor cost was lower

than in the preceding cases. The price of pipe was $15.80 per ton. The following is the cost per lineal foot.

Diameter.	Weight per ft. lbs.	Pipe.	Labor.	Total.
20 ins.	211	$1.67	$0.09	$1.73
24 ins.	223	1.92	0.17	2.09
30 ins.	367	2.90	0.22	3.12
36 ins.	467	3.69	0.42	4.11
42 ins.	634	5.00	0.70	5.70
48 ins.	797	6.29	0.72	7.01
60 ins.	1,263	10.61	1.26	11.87

In the R. R. Gazette, Vol. 19, p. 122, cast iron culverts made in quadrants bolted together are described. The quadrants are provided with outside flanges, and with a recess in which tarred rope smeared with neat cement is placed before bolting together. No skilled labor is required. A 7-ft. culvert, 50 ft. long, contained 45 short tons of cast iron. The labor of unloading it from the cars was $17.50, or 40 cts. per ton, and the labor of putting it in place was $150, or $3.30 per ton.

Corrugated Metal Culvert.—The metal culvert was 18 ft. long and 4 ft. in diameter, the bottom being 6 ins. lower than the grade line of the ditch. Concrete solid walls were built rising from bottom of culvert to the ground surface, and extending into both banks. These walls were 20 ins. thick to top of pipe, 18 ins. thick to within 8 ins. of the surface, and the top 8 ins. was 12 ins. thick. The top 8 ins. was of 1:6 mortar and the remainder was of 1:4:4 broken tile concrete. Condemned tile was broken into 1 to 2-in. pieces. The walls were 12 ft. long at the level of the top of the pipe and 20 ft. long at the surface. The forms were constructed by first placing the plank parallel to the slopes until the concrete was carried to the top of the pipe, and up the slopes to the surface. After this had hardened for 24 hours, the planking was taken down and laid horizontal to construct the center part of the wall. This method of constructing the forms required a minimum of lumber and no cuting of the lumber. The cost of the culvert was as follows:

1 corrugated metal pipe, 4 ft. diam., 18 ins. long, $6 per ft.	$108.00
Hauling culvert from depot, 2 men and team, 2 hrs. at 65c per hr.	1.30
Labor, preparing ditch for culvert, 2 men 3.5 hrs. ea. at 30c	1.40
Bolting pipe together and lowering into ditch, 3 men, 3.5 hrs. at 20c	2.10
37.5 sacks of cement at 75c per sack	28.12
5.6 cu. yds. of sand at $1.50 per cu. yd	8.40
5 cu. yds. broken tile at 54c per cu. yd. for breaking	2.70
Labor of building abutment, 82 hrs. at 20c per hr.	16.40
2 men and team grading, 5 hrs. at 65c per hr.	3.25
Incidentals	3.00
Total	$175.64

Cost of Tearing Down a Small Bridge.—A small highway bridge of 35-ft. span, and roadway 25 ft. wide, contained 10 tons of iron in the trusses and 4,650 ft. B. M. in the flooring. The flooring was 3-in. oak plank on 3 x 12-in. stringers spaced 2 ft. apart, and two

8 x 14-in. stringers under an electric car track. It took 6 men and 1 foreman 3 days to tear down and store the bridge, at a cost of $36.

A wooden footbridge, 6 ft. wide and 100 ft. long over a creek, contained 4,000 ft. B. M. It took 8 men and a team 3 hrs. to tear down and remove this structure, which was essentially a light temporary trestle floored with 3-in. plank. The cost was $1 per M for this tearing down. The same gang had originally erected this structure at a cost of $3.75 per M.

Cost of Moving a 65-ft. Bridge and New Abutments.—A steel highway pony truss bridge of 65-ft. span and 16-ft. roadway had been erected upon timber pile abutments that had rotted badly. New abutments were built adjoining the old abutments, by driving 12 iron piles for each abutment and its wing walls. These piles were of old steel rails 30 ft. long, and were driven 20 ft. deep. A small pile driver operated by 5 men and 1 horse averaged 8 piles per 10-hr. day, for 3 days. Then 1 day was spent in building a falsework, and 2 more days raising and shifting the bridge from its old abutments to the new. The cost of pile driving was $30, or $1.25 per pile. The cost of building the falsework was $10, and the cost of moving the bridge was $20.

SECTION XIII.

STEEL AND IRON CONSTRUCTION.

Need of More Printed Data.—Notwithstanding that this has been called the Age of Steel, there have been fewer articles printed on the cost of steel work than on any other class of engineering construction. We have had books without number on the design of steel bridges, but next to nothing in those books on the itemized cost of steel bridges. Indeed, aside from the articles on the cost of steel bridge erection published in *Engineering-Contracting* within the last four years, practically nothing on this important subject has ever appeared in the engineering journals. In the section on Bridges will be found the data just referred to. For some time to come, too much cannot be published on the methods and cost of steel construction of all kinds.

Cross-References.—To avoid duplication, it seems advisable not to give in this section any of the data on steel and iron work given in other sections of the book, but rather to provide a very complete index of Steel Construction and another of Iron Work. Such an index will be found in the back of this book.

As an indication of what will be found on steel and iron in the various sections, it may be well to bear in mind the following facts: (1) The cost of shaping and placing steel for reinforced concrete is given in the sections on Concrete, on Sewers, on Bridges, on Buildings, etc.; (2) the cost of laying cast iron and steel waterpipe, the erecting of steel standpipes, etc., will be found in the section on Waterworks; (3) the cost of building steel bridges and viaducts, iron and steel culverts, etc., will be found in the section on Bridges; (4) the cost of laying steel rails will be found in the section on Railways; (5) the cost of putting on expanded metal lath, galvanized iron siding, tin roofing, etc., will be found in section on Buildings.

As above stated, use the index under Steel Construction and under Iron Work.

Cost of Pneumatic Riveting.—Mr. A. B. Manning gives the following data:

One 12 hp. gasoline driven air compressor (Fairbanks, Morse & Co.); two galvanized iron water tanks; one galvanized iron gasoline tank; one large main reservoir; one small auxiliary reservoir; hose and fittings; cost mounted on car $1,073. Operating at 90 lbs. pressure this compressor furnished air for 3 pneumatic hammers, 2 drills, 2 rivet forges, and 1 blacksmith forge, all working at one

time. The 3 hammers and the 2 drills cost (in 1899) $627. The cost of repairs for 16 months averaged $3 per month on this $1,700 plant. The cost of operating was as follows per day:

15 gals. gasoline, at 11.2 cts.	$1.68
Oil, waste, etc.	0.12
Depreciation (estimated on 20% basis, for 313 days)	1.09
Repairs	0.11
Total per day	$3.00

On the basis of running 3 rivet hammers, this is $1 per hammer for power.

Power for one hammer per day	$1.00
Oil for one hammer per day	0.12
2 men driving rivets, at $2.40	4.80
1 man heating rivets	2.20
Total for one hammer per day	$8.12

A pneumatic riveter on bridge work averages 500 rivets per 10-hr. day for $8.12, or $1.62 per hundred rivets. On one day 700 rivets were driven, by using an additional man to take out fitting-up bolts, etc. The above costs are based upon the erection of 22 bridge spans, aggregating 2,455 lin. ft. and 80,065 rivets.

The cost of riveting by hand is as follows:

2 men, at $2.40	$4.80
2 men, at $2.20	4.40
Total per gang per day	$9.20

Such a gang averages 250 rivets per day, which is equivalent to $3.68 per hundred rivets.

Mr. F. S. Edinger states that with a 12 hp. gasoline driven compressor and an 80 cu. ft. air receiver, five longstroke hammers were operated at one time without reducing the air pressure below 75 lbs. The five hammers when driving 50 rivets (⅞-in. diam.) per minute are using air only about 5% of the time. The same compressor will run 2 hammers and 2 drills at one time. The drills use more air than the hammers as they run uninterruptedly. The drills can be used for boring timber by inserting an auger in place of a drill; but the speed is not high enough for wood boring. Two men and a heater form a riveting gang and they drive twice as many rivets as three men and a heater drive by hand. The cost of fitting up and riveting on new steel bridges (all rivets ⅞-in.) was 35 to 40% less than if the work had been done by hand, and the work was done better.

Pneumatic and Hand Riveting.—Mr. Charles Evan Fowler gives the following. On the Northwestern Elevated Ry. construction, Chicago, percussion riveters were used, driving as high as 500 rivets per day, with three men at the riveter and a heater. Hand gangs on that work averaged 300 rivets.

In reinforcing the Manhattan Elevated, N. Y., the record is 465 to 525 rivets per day with percussion machines, and careful tests showed that it required 5 cu. ft. of free air per ¾-in. rivet.

On the Boston Elevated Ry., in 1900, the long gun type of Boyer riveters were used. Owing to the cramped condition of much of the work, only 300 rivets per day were driven, two men at a riveter and a heater at the forge. Hand gangs drove as many as 400 rivets per gang per day.

Cost of Erecting Steel in N. Y. Subway.—The cost of erecting the steel posts and girders in the N. Y. subway was as follows on one section where 4,300 tons were erected:

	Per ton.
Labor trucking	$ 1.47
Labor placing and riveting	11.68
Labor painting	0.90
Materials for painting	0.70
Materials for placing and riveting	0.90
Power	0.30
Total	$15.95

Iron workers were paid $4 for 8 hrs.; iron foremen, $5; painters, $2. There was 1 foreman to every 10 men.

The contract price for erecting and painting was $13 a ton, so that money was lost by the contractor on this work. The men worked under difficulties, and with little energy.

Weight of The Eiffel Tower.—The Eiffel Tower weighs 7,500 tons. It is 906 ft. high, 33 ft. square on top, and 330 ft. square at the base. The power plant is 500 hp.

Cost of a Gas Pipe Hand Railing.—A gas pipe hand railing for a small stone-arch bridge was made of three lines of 1½-in. pipe rails and posts. The weight of the pipe was 800 lbs. for 100 lin. ft. of railing (50 ft. on each side of the bridge). The cost was as follows:

100 lin. ft. of railing ready to erect	$65.00
Hauling 1½ miles	0.60
1 qt. asphaltum paint	0.20
Paint brush	0.20
9 lbs. sulphur, at 8 cts.	0.72
Iron kettle to melt sulphur in	0.40
Labor erecting railing, 17 hrs., at 35 cts.	5.95
Labor erecting railing, 2 hrs., at 15 cts.	0.30
Total for 100 ft. of railing	$73.37

The principal cost of erecting was the drilling of 48 bolt holes (½ x 2 ins.) in the stone coping. The bolts that passed through the cast-iron post bases were held with sulphur. The posts were made of 1½-in. gas pipe, crosses and tees. The 1½-in. pipe measured about 2 ins. outside diameter, which is a good size for hand railing.

On another job 100 lin. ft. of hand railing were built along an embankment. The railing was made of 3 lines of ¾-in. gas pipe (1-in. diam. outside) made as above described, except that each post was fastened to an oak plank buried in the ground, and an

guys and 4 sets of ¾-in. blocks for hauling in guys, and bracing the stack inside was $250. A gang of 8 men at $1.30 per day and one top man at $2.25 per day were employed, with some extra men for about 2 hours.

The erection as described was planned and carried out by Mr. George B. Nicholson, a hoisting engineer. Incidentally it may be stated that Mr. Nicholson undertook the job after it had been rejected as impossible by expert riggers. We consider this a rather remarkable job of hoisting engineering. Only one man, Mr. Nicholson, was a skilled man, all the others being ordinary laborers with no experience in hoisting and rigging. In addition the method of rigging the tackle, using only one line to run through three sets of blocks on the stack and one block on the mast, is notable. We are indebted for the information from which this description has been prepared to F. W. Raymond.

Cost of Cast-Iron Work.*—The total weight of the cast-iron stairway trim, manhole covers, etc., in the U. S. Government Printing Office at Washington, D. C., was 80 tons. The total value in place was $221.25 per ton. The cost of erection was $62.50 per ton, which is an enormously high labor cost, attributable to the fact that the work was done by Government forces.

The wages paid per eight-hour day were as follows:

Superintendent	$5.25
Foremen	4.25
Ironworkers	3.45
Helpers	1.60
Smith	2.25

The total weight of the cast-iron frames and baseboard in the building was 743.4 tons of the total contract amounting to $107,800 or $145 per ton. The cost of erection was practically $23 per ton.

Cost of Shop Drawings for Steel Work.†—Mr. R. H. Gage gives the following:

The data were gathered by the writer while in charge of the Drafting Department of A. Bolter's Sons' Structural Steel and Iron Works, of Chicago, Ill., during the years 1904, 1905 and 1906.

The works are divided into three different departments, the Structural Shop, the Architectural Shop and the Foundry. The Structural Shop has a capacity of 800 tons per month. The Drafting Department employs on an average seven or eight engineers. All the work is standardized with regard to details to as great an extent as possible, in order to decrease the work in the Drafting Room, yet not to such an extent that it would be difficult for the shop men to read the drawings. For example, all beam, steel and cast iron column connections, with the exception of special cases, are not drawn and dimensioned completely, but merely indicated. The shop and drafting room have been provided with a set of the

*_Engineering-Contracting_, Mar. 18, 1908.
†_Engineering-Contracting_, Aug. 28, 1907.

firm's standards, which have all these connections drawn out completely with dimensions and which give lists of the material.

The data here presented were taken from a great variety of work, such as public and private school buildings, churches, breweries, malt houses and elevators, grain bins, warehouses, libraries, hospitals, apartment buildings, factories and manufacturing plants, train sheds, mill buildings, office buildings, electric lighting plants and pumping stations.

Table I shows the character of the buildings and also the average cost of preparing the drawings. The cost of drafting material and blue prints is not included. Where the material for the work is to be ordered from the mill and not taken from stock, the cutting bills or mill orders are taken as being part of the details. Table II (not reproduced here) shows the particulars of the buildings from which the data in Table I were derived.

TABLE I.—COST OF SHOP DRAWINGS.

Type.	Character of Building:	Av. cost per ton.
1.	Entire skeleton construction, i. e., loads all carried to the foundation by means of steel columns	$1.45
2.	Interior portion supported on steel columns; exterior walls carry floor loads and their own weight	1.22
3.	Interior portion carried on cast iron columns; exterior walls support floor loads as well as their own weight	0.70
4.	No columns and floor beams resting on masonry walls throughout	0.85
5.	Structure consisting mostly of roof trusses resting on columns	2.47
6.	Structure consisting mostly of roof trusses resting on masonry walls	1.25
7.	Mill buildings	2.56
8.	Flat one-story shop or manufacturing buildings	0.74
9.	Tipples, mining structures or other complicated structures	4.38
10.	Malt or grain bins and hoppers	2.47
11.	Remodeling and additions where measurements are necessary before details can be made	1.87

There is always a noticeable decrease in the cost of details when the plans for the iron work are made and designed by an engineer and separated from the general plans. On comparing the cost of picking out the structural steel and making the shop drawings from the architect's plans and the engineer's plans, it was found that the cost of the former is on an average of 35% higher than the latter. Where the engineer's plans are made with no dimensions, with only the outline and sections given, it being necessary to refer to the general plans for the location and dimensions, there is no saving of time, and the detailing runs as high as on the architect's plans.

Inaccurate plans, where the draftsman is continually finding errors, cause an increase in the cost, as it is necessary to wait and refer the matter to the architect; and in most cases he, in turn, has to check over his plans before he can settle the question, all of which causes considerable delay and takes time that might otherwise be spent in making the drawings.

The cost of structural steel details depends on so many things that it is hard to set any fixed rule for determining what this cost is. The type of the building is the first consideration; then the architect and engineer, their methods of drawing up their plans; and finally the detailing drafting force one is obliged to depend upon.

Cost of Sheeting a Foundation Pit with Steel Sheet Piling.[1]— The old U. S. Custom House on Wall St. in New York City was reconstructed in 1908 for the use of the National City Bank. The old building was four stories high with heavy stone walls founded on spread footings. In addition there were on the front 16 heavy stone columns, 12 in a row across the front and 4 inside the entrance. The plans for reconstruction involved the removal and renewal of everything inside the main walls which were to be preserved. The new interior was planned to be of steel frame construction, the foundations for which would be some 7 ft. to 12 ft. below the level of the footings of the old walls and columns.

The problem to be solved was the construction of the new and deeper foundations without undermining the old footings or causing any settlement which would crack or otherwise injure the structure supported by these footings. The soil was a mixture of clay and sand containing many 10 and 12-in. stones. It also carried considerable water. Obviously careful precautions were under the conditions necessary. The plans adopted were to drive a row of Wemlinger steel sheeting all around the interior of the building about 12 ins. from the edges of the footings and with its top left about 18 ins. higher.

The sheeting used was the Wemlinger corrugated double, consisting when driven of two thicknesses of 3/16-in. steel sheets; each sheet was 24 ins. wide and 14 ft. long. The two sheets were driven together, thus sheeting a width of 34 ins. each driving. The driving was done in two steps or moves. The first step was to a depth of 3 ft. and was made with an Ingersoll-Rand Type D sheet pile driver. The remaining depth of about 11 ft. was secured with a Vulcan No. 3 steam hammer having a 2,000-lb. ram. A steel plate was placed over the pile and on it was set a 2-in. steel block which took the blow of the ram.

The mounting of the drivers was novel. A 1¼-in. steel cable was stretched horizontally along the inside of the old wall and from it were suspended the two hammers and a light tackle for handling the sheeting. The lighter hamper was suspended on a differential hoist. The Vulcan hammer was suspended from a block operated by a crab so mounted that the mounting formed a guide and prevented the swing of the hammer. The maximum span of suspending cable used was 190 ft.

Inside the driven sheeting there was built a wall of concrete. Pockets or sections about 10 ft. wide were excavated so as to lay bare the sheeting at regular intervals and have a supporting core between each pair of sections. As soon as the excavation of each

---

[1] *Engineering-Contracting,* Oct. 13, 1909.

pocket had been carried down about 3 ft. a 12 x 12-in. waling timber was set against the sheeting and braced back to the rear and bottom of the pocket. The excavation was then carried down to a depth of 8 or 9 ft. and a wall or block of concrete was deposited in the pocket against the piling. After this concrete had set the cores between pockets were excavated and in turn filled with concrete. This completed a concrete wall 5 ft. thick entirely around the sheeting inside. The remaining excavation went on inside this wall and was accomplished with absolutely no disturbance of the old masonry walls and footings.

The contractors for the sheeting were the Wemlinger Steel Piling Co. of New York, N. Y. The cost of the work to the contractors was as follows:

Rental of Plant:	
Boiler at $3 per 8-hr. day	$ 134.37
1 Ingersoll-Rand hammer at $1.50 per day; 1 Vulcan hammer at $6 per day	256.36
Total rental	$ 390.73
Repairs to plant	184.18
Permanent plant	319.09
Coal at $5.76 per net ton	80.52
Supplies	22.64
Labor:	
Driving; House shorers at $3.50; Foreman at $4.50	$1,089.32
Unloading piling laborers at $2.25	32.00
Steam; 1 engineman at $4.50; 1 fireman at $2.25	112.91
Constructing and erecting plant	65.56
Total labor	$1,299.79
Freight and Haulage:	
Freight	$ 334.01
Hauling 105 tons of sheeting	179.76
Hauling supplies and equipment	38.16
Total	$ 551.93
Liability insurance	$ 50.77
Grand total	$2,899.65

The amount of sheeting driven was 638 lin. ft., 14 ft. long, or 8,932 sq. ft. Including the cost of the sheeting not given above, the cost was $0.885 per sq. ft. Exclusive of freight and hauling charges on sheeting, $513.77, which may be charged to the cost of sheeting ready for driving, the cost of driving was $2,385.88, or $0.267 per sq. ft. The labor cost of driving was $0.146 per sq. ft.

In further comment on these costs the Wemlinger Steel Piling Co., which furnishes them to us, writes as follows:

"You will note that the cost of doing this work was somewhat high which, in the first place, is explained by the fact that we had

to employ union labor at high wages. Furthermore the expense for rental and repairs of equipment were higher than they would have been if we had been regularly equipped for doing this class of work. This was, however, a contract which we took mainly for the purpose of introducing and demonstrating our material. You will note that we have charged the entire cost of the permanent plant against this contract, the reason for this being that most of the plant was purchased especially for this work. Another reason for the high cost is our own comparative inexperience and that all the labor employed, which in spite of the fact that members of the House Shorers' Union were employed, proved rather ineffective. We believe that considering the experience we have now we could easily do the same work for at least 25% less cost."

Cost of Driving Steel Sheet Piling for Cut-off Wall of a Dam.*— Mr. Carl P. Abbott is author of the following:

The construction of a concrete dam, with tide gates, to replace an old wooden dam on a salt marsh was completed in the summer of 1906 by the Queens County Water Co., of Far Rockaway, N. Y. In planning the new work considerable thought was given to the kind of sheet piling that would best answer the purpose of keeping the water from getting underneath the dam and the choice was made of steel sheet piling of the form manufactured by the United States Steel Piling Co., of Chicago, Ill. Besides supplying the requisite water-tight wall, this piling seemed likely to be more durable and more surely driven and certain to add considerably to the strength of the structure.

The piling was driven lengthwise of the dam and in the center, and, as a turf dike was carried from each end of the concrete dam to shore, the piling was carried five lengths beyond the concrete to form a sort of bond at the junction of concrete and turf. There were two lengths of piling used, 25-ft. and 18-ft.; the 25-ft. lengths at each end of the dam and one length between each gate, and the 18-ft. lengths under the gates. The 25-ft. lengths were driven flush with the surface of the marsh, so the 18-ft. lengths were driven flush and then the pile-driver was moved back over the line and the 18-ft. lengths run down 7 ft. further with a 10-ft. piece used as a runner by bolting a couple of wrought-iron plates on the lower end to hold it on the pile. A half-round pine filling strip was used. The material encountered was about 8 ft. of turf, then 3 or 4 ft. of sand, then a streak of hard pan and then sand again, and where the driving cap was used the piles were not battered at all. Some bids were put in for the driving, but as they looked pretty high we decided to do the work ourselves.

We took an old well drilling machine, and with very little carpenter work it made a good pile-driver. A 1,500-lb. hammer was used and a driving cap made by the United States Steel Piling Co. was also used for most of the work.

The driving gang usually consisted of three men, who were taken from the company's force and were very quickly broken in, with

*Engineering-Contracting, Jan. 16. 1907.

some extra men for a part of the time to haul the piles across the channel from the railway track and to move the machine to the job. The cost of driving given below includes hauling the piles over and moving the machine to the job. The cost of moving the machine away was not included, as the machine and boiler were used for other purposes for some time after.

The cost of labor, supplies, etc., was as follows:

20 days' labor at $2.25	$ 45.00
9½ days' labor at $2.10	19.95
8½ days' labor at $2.00	17.00
2 days' labor at $1.75	3.50
34 days' labor at $1.50	51.00
Total labor cost	$136.45
17 days' use of machine at $2.00	34.00
2 tons coal at $5.00	10.00
Superintendence at 5 per cent	9.00
Total machinery and supplies	$ 53.00
Grand total	$189.45

There were 55 piles each driven 25 ft., making a total of 1,375 lin. ft. driven at a cost of 13.8 cts. per ft. for the driving. As the men were inexperienced it cost more to drive the first few piles than afterward, and if the same number were to be driven again the cost of driving would be very much decreased. As a whole, the steel piling was very satisfactory and easy to handle and drive, even by men not accustomed to that sort of work.

Cost of Steel Sheet Piling for Cofferdam.*—The cost of 140 steel sheet piles in place was as follows. The piles were 26 ft. long, driven to an average penetration of 22 ft.

The work was done by the U. S. Reclamation Service.

The type of piling is that manufactured by the Carnegie Steel Company for the United States Steel Piling Co., of Chicago. The piling cost at the factory is 70 cts. per lin. ft., and as its weight is 35 lbs. per running foot, the cost therefore was 2 cts. per lb. The freight rate from the factory at Pittsburg to Whalen, Wyo., was $1 per 100 lbs., thus making the total cost f. o. b. cars at Whalen, about $1.05 per lin. ft.

The line of piles under consideration was driven in August, 1907, and forms a part of the south side of the cofferdam used in the construction of the concrete diversion dam on the North Platte River, at the head of the Interstate canal. None of the piles were driven under water, and the material into which they penetrated consists of sand and coarse gravel. The piles were dragged from the railroad siding to the river bank, and carried across the river on cables.

The pile-driver outfit used was a Lidgerwood single drum 20-hp. hoisting engine and a 2,800-lb. hammer, having an average drop of 8 ft. When no hindrance occurred by accidents to the machinery, the average number of piles driven per twelve hours was 27, with an exceptionally high run on August 9 of 29.

*_Engineering-Contracting_, June 10, 1908.

The regular pile-driving crew consisted of one foreman, one engineer and four laborers. Each of these men received 35 cts. an hour for his work except in transporting the piles from the railroad station to the driver, in which case the laborers were paid for at the rate of 25 cts. an hour and teams at the rate of 20 cts. per hour. The total labor cost of unloading and moving the piles from the railroad to the driver was $53.25, making a unit cost per linear foot of pile of $0.015. The total labor cost for driving was $190.05, making a unit cost of $0.052 per linear foot of pile.

Below are tabulated the total and unit costs of the piles in place distributed under the headings of plant depreciation, labor, materials and supplies. The depreciation on the engine was about 2% of its original cost, while that on the driver was about 30% of its original cost, including repairs made on it. The charge for materials contains in addition to the piling and freight thereon, $28 worth of wood fillers used in connection with the piling. The charges under supplies consist of coal and oil for the engine and labor for carrying drinking water. Six tons of coal were used, at $5.50 per ton.

Distribution of costs.	Total cost.	Unit cost per pile.	Unit cost per foot of pile	Unit cost per foot of penetration.
Plant depreciation	$60.00	$0.416	$0.016	$0.019
Labor	243.30	1.742	0.067	0.079
Materials	3,850.00	27.508	1.058	1.250
Supplies	44.18	0.312	0.012	0.014
Total	$4,197.48	$29.978	$1.153	$1.362

Cost of Driving Some Steel Sheet Piling.*—The work for which the costs are given consisted of the construction of cofferdams, preliminary to building the substructure of a double track bridge for the Norfolk & Western Ry. at Chillicothe, O., the work being necessitated by a change of line at that point.

The cofferdams were built of the steel piling manufactured by the U. S. Steel Piling Co., of Chicago, the same piling being reused for the three piers. The cofferdam was 16 ft. x 62 ft., and 156 pieces of piling, 16 ft. in length, were used. The piling was driven to a depth of 14 ft. below water level, the water being from 3 ft. to 6 ft. deep. The material into which the piles were driven consisted of coarse gravel ranging in size from ¼ in. to 8 ins. in diameter.

In driving the piling for the first cofferdam, the piling was picked up from the shore by means of a steam derrick and put into place for the pile-driver. An ordinary drop-hammer pile-driver, rigged on a scow, and having a 2,000-lb. hammer, was used.

The piling in the first cofferdam was driven in three days, the crew and their wages per 10-hr. day being as follows:

Foreman	$ 5.00
Engineer on derrick	3.00
Tagman	2.00
Engineer on pile driver	3.00
Six men handling pile driver and boat	10.50
Total	$23.50

*Engineering-Contracting, June 6, 1906.

The total cost of driving the 156 pieces of piling was $70.50, or 45.2 cts. per piece.

The same crew constructed the next cofferdam, five days, however, being consumed in the work. The main reason for the difference of time was in the facilities for handling the piling. In this cofferdam the piling was picked off the shore by the derrick, placed on the scow on which the pile-driver was rigged, and then taken to the site of the cofferdam, where it was placed in position by the driver instead of by the derrick as in the first case. The cost of driving the piling for this cofferdam was $117.50.

The above figures do not take into account fuel and plant rental, nor the cost of braces and waling which were used as described below.

In order to make the cofferdam ready for pumping out a 6-in. x 8-in. waling piece was bolted to the inside of the sheet piling and braces placed across from side to side at intervals. From three to five braces were used along the top, but were used at no other point.

We are indebted to Mr. L. E. Sturm, Railroad Contractor, of Columbus, O., for the information in the above article and for the illustrations.

Cost of Steel Sheet Piling in a Cofferdam and in Caissons.*— As it is only within the last few years that steel sheet piling has come into general use, the experience of the William P. Carmichael Co., Engineers and Contractors, of Williamsport, Ind., with this form of piling will be of interest to our readers. About a year ago this firm purchased enough sheet steel piling to construct a cofferdam of a total perimeter of 132 ft. and a depth of 12½ ft. This was first used in the construction of a pier foundation for the Wabash R. R., in the Huron River, near Detroit, Mich. The water at the point where the pier was to be constructed was from 5 to 8 ft. deep. The bottom consisted of from 2 to 3 ft. of alluvium, on top of a blue sandy clay, partaking in a measure of the nature of quicksand. This being the company's first experience with steel sheet piling, they attempted to assemble the units and complete the box before driving. This was finally done, but at the expense of a good deal of unnecessary labor and time. At first it was proposed to drive six pieces at once by striking a cap covering that many piles, but it was soon found that a pretty stiff blow from a 2,600-lb. hammer was required to drive two at a time. The piles were driven to a depth of 3 ft. below the proposed bottom of concrete.

After the piles were driven to the required depth, an attempt was made to pump out the water from the caisson. A 6-in. centrifugal pump was used, but failed to lower the water level more than a few inches. An outer row of 2-in. wooden sheet piling was then driven about 5 ft. from the steel box, and the space filled with clay and puddled. This served its purpose, for with the exception of a few

---

**Engineering-Contracting*, May 9, 1906.

leaks, very little water came into the caisson. An attempt was made to stop these leaks with clay, but owing to the presence of sand in the clay, the attempt was only partially successful.

The piles were withdrawn in practically as good condition as when driven, so that the cost of material was only charged at 2% on account of the foundation. After the first piece was loosened, the piles in the foundation were withdrawn at a very small cost. Owing to an accident to the foremen, no accurate cost account was kept of this work.

The next use of the steel piling by this firm was in caissons for four piers for a highway bridge across the Wabash River; for this

Fig. 2.—Driving Steel Piling.

work some excellent cost data are given further on. Three of these piers were upon an island. At the time the work was done these sites were not covered by water. The piles were driven into coarse sand and gravel. The plant used for the work consisted of a small land pile-driver, having derrick and steam hoist for handling the hammer, which weighed 2,000 lbs. A steel bound wood driving head was fitted between leads and was used to protect the head of the piles in driving. An illustration of the plant is given in Fig. 2.

In pulling the piling, it was often necessary to use a pulling lever with a 4 to 1 purchase, the derrick and hoist being hitched to lever. On this job strips of wooden batten were used in the batten or the groove between each two steel piles, and in this way the coffer-dam was made practically watertight. So much so, indeed, that

an ordinary diaphragm pump would have handled all the water except for what came up from the bottom of the pit.

The piling was found to be in good condition after being pulled, only two pieces being in bad shape. And those could be fixed up by an ordinary blacksmith at a cost not exceeding one-half of the value of the pieces.

Now as to the cost of driving and pulling the piling. Below is given the cost record on the third pier. Work on this was begun Oct. 6, 1905, and completed Oct. 11. The gang and rig worked a total of 55 hours and finished driving the piling in 4½ days. Some days, however, the gang worked for 15 hours, as is shown in the labor cost below. The wages of laborers were from 17½ cts. to 20 cts. per hour, depending upon proficiency and length of service. The enginemen and derrickmen received 22½ cts. per hour, and the foreman on the job for which the data below are given was paid 25 cts. per hour. The low rate of wages paid to the foreman was due to the fact that he was a new man in that position and did not have to assume much responsibility, Mr. M. C. Andrews, of the contracting firm, being in charge of the work in person.

The cost of driving and pulling was as follows:

Driving:	
Labor	\$ 93.00
Use of machinery, fuel, etc., 5 days	15.00
Total for driving	\$108.00
Pulling:	
Labor	\$ 50.00
Use of machinery, fuel, etc., 8 days	10.00
Total for pulling	\$ 60.00

As 130 piles were each driven 11½ ft., or a total of 1,495 ft., the cost per foot of pile for driving was 7.2 cts.; the cost per foot of pile for pulling was 4 cts., making the total cost for driving and pulling 11.2 cts. As is shown in the table below this 11.2 cts. also includes the cost of straightening bent and warped piles. The labor cost of driving the piles can be further summarized and in the tabulation below is given the rate of wages and the hours worked each day by the various classes of labor.

Rate.	Labor Cost.	Driving.	Straightening piles.
Oct. 6	\$13.54	\$13.54	....
Oct. 7	28.92	21.00	7.92
Oct. 9	17.70	14.00	3.70
Oct. 10	22.17	22.17	....
Oct. 11	10.68	10.68	....
Totals	\$93.01	\$81.39	\$11.62

The work accomplished each day was as follows: Oct. 6, drove 21 piles and worked straightening bent piles; Oct. 7, drove 25 piles and finished straightening bent piles; Oct. 9, drove 30 piles; Oct. 10, drove 35 piles; Oct. 11, drove 19 piles.

In conclusion we would call especial attention to the illustration showing the pile-driving plant. It will be noted that the hammer

was suspended from the boom of a derrick, and that the engine used to operate the derrick was also used to drive the piles. The hammer is shown outside the leads of the pile-driver, but, in driving, it is placed between the leads. In fact, the same engine operated the derrick, shifted the driver from place to place, placed the pile in position and handled the hammer. The fall was not usually greater that 20 ft., and consequently very little damage was done to the derrick.

The steel piling used on the above work was made by the United States Steel Piling Co., of Chicago, Ill. We are indebted to the William P. Carmichael Co. for the information given in this article.

Cutting Off Steel Sheet Piles with the Electric Arc.*—In the interesting paper on steel sheet piling by Mr. Wm. A. Fargo, which was published in our issue of May 1, 1907, some data were given of the use of the electric arc in cutting off steel piles at the New Hoffman House foundation work in New York City. Since the publication of this article we have received from Mr. Frank C. Perkins, Electrical Engineer, of Buffalo, N. Y., a photograph of the work in progress, together with a brief account of the apparatus employed.

The steel piles being cut are ⅝ in. thick in the web and 3 ins. at the interlocking points. It is stated that the time required in burning the ⅝-in. steel is four minutes per foot and the time taken at the interlocking points is said to be 8 minutes.

The arc light carbon is held in a metal clamp fastened to a metallic rod and socket, which is in turn bolted to a long wooden pole, the cable conducting the current being flexible and connected to the metal clamp of the carbon terminal. The steel to be cut is connected to the other conductor from the alternating current circuit. As shown in the illustration the men are protected from the extreme heat and terrific glare by goggles and asbestos masks as well as gloves, as it has been found that the carbon fumes produced by the high power electric arc, affected the lips and other parts of the face and hands.

About 1,200 amperes are being utilized at 50 volts pressure, alternating current being employed stepped down to the above voltage from the high pressure service of 2,500 volts. Single phase alternating current is employed, taken from the street service mains, the frequency being 60 cycles per second.

Referring to this work Mr. Fargo, in his paper says: "The cost of cutting steel piling with current at 10 cts. per kw. and the attendant at 50 cts. per hour, is stated to be as follows per foot of piling cut:

Cost of current	$2.56
Labor	0.40
Total	$2.96

Engineering-Contracting, June 26, 1907.

This is rather high, and the hack-saw would probably be cheaper. However, with current at say 3 cts. per kw.-hour the cost per foot would be but $1.17. Even at this rate, with labor competent to use a hack-saw at 25 cts. per hour, the saw would be the cheaper."

Cost of Driving Steel Sheet Piling.*—A valuable record of experience in driving steel sheet piling in hard soils was given recently by Mr. Wm. A. Fargo, Civil and Hydraulic Engineer, of Jackson, Mich., in a paper read before the Michigan Engineering Society. Through the kindness of Mr. Fargo we have received some additional cost data on steel sheet piling work, and these, with the original paper, are printed in the following paragraphs:

Steel sheet piling is used for purposes entirely similar to wood sheet piling, but is much more certain in results obtained. The principal applications of steel sheet piling are as follows: (1) Cofferdams: For building and structure foundations, including bridge piers and abutments. Also for mine shafts where the piling may be forced down in the manner of a caisson or shield. (2) Dams: For the dam itself, as for low dams; thus requiring no other cofferdam or pumping out of the foundation pit. As a cut-off across a valley under a dam or beneath a core wall. As a permanent enclosing wall down to an impervious stratum for the masonry structure of the dam, or for power house or other building not necessarily part of a dam; or as a downstream toe protection only. (3) Retaining Wall: Temporary or permanent as required in building footings close to an existing structure. This use is essentially similar to the cofferdam.

The types or varieties of steel sheet piling are as follows: (1) Special rolled sections, composed of forms requiring special rolls for producing the piling. If there are return bends, or flanges transverse to the plane of rolling, the piling must pass through a series of special rolls. (2) Built-up sections. Usually built up from standard structural steel shapes. These may consist of single webs with riveted interlocking members, or of double parallel webs held in relative position by bolts and pipe separators. The double-web sections are usually driven alternately with single web members. A number of forms of steel sheet piling are shown in Fig. 1. The following points need to be considered in selecting a design of piling for any work:

Water-Tightness.—In deep cofferdams a prime requisite is water-tightness. The clearance of interlock of adjoining piles must therefore be reduced as much as possible and still allow of driving. The clearances used on the built-up types are from ⅛-in. to ¼-in. all around the interlock. In hard soils ¼-in. is none too much. In many sections of piling over 15 ft. or 20 ft. long there will be found such kinks and crimps, partly the result of handling on and off cars, that driving with a tight interlock is a serious problem. With such a close interlock, piles not true or perfect in alignment often refuse to drive when there is encountered a stratum of hard-pan or layer of small boulders. Under such conditions piling often

***Engineering-Contracting*, May 1, 1907.

refuses under the heaviest drop or steam hammer. If driving is persisted in it will result in the crippling of the pile either at the top or bottom. Crippling at the bottom means usually an escape from the interlock and a curving to one side exactly like a clinched nail except that the curve of the clinch may have several feet radius.

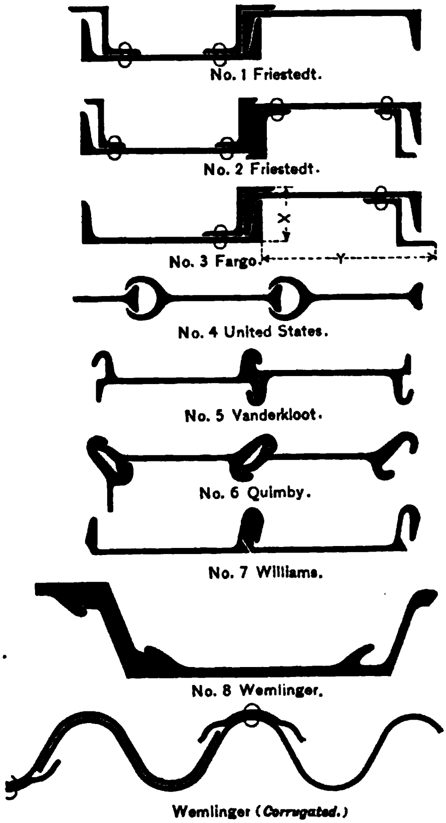


Fig. 3.—Representative Steel Sheet Pile Sections.

Stiffness.—In locations where there are encountered strata of hard material such as often occur in river valleys, where the drift has been eroded and redeposited, the steel piling to be a success must possess considerable stiffness laterally to prevent crippling. There-

fore examine the radius of gyration of the proposed section of piling. It is the writer's experience that for hard driving the free or unengaged edge (see X in No. 3, Fig. 3) of the pile being driven should be of a width (at right angles to the web) of one-third to one-half of the width of the engaged web (see Y in section No. 3, Fig. 3).

Methods of Driving.—The friction of long lengths of steel piling, with their inevitable crimps, will make necessary a heavy hammer, say a 4,500-lb. ram on a steam rig or a 3,000-lb. or heavier drop

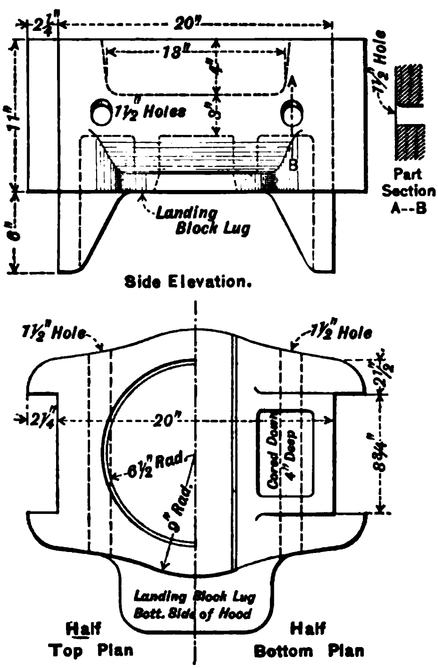


Fig. 4.—Cast-Iron Follower for Driving Steel Sheet Piles.

hammer. Most of the writer's experience in driving steel sheeting has been with the heaviest No. 1 Vulcan steam hammer (4,500-lb. ram); total weight of hammer resting on the pile, 10,000 lbs. These hammers are adjusted to strike about 65 times per minute with 3½-ft. stroke. These large (No. 1) Vulcan hammers are preferably fitted with a "McDermid base" consisting of a 1⅝-in. circular steel plate about 13 ins. in diameter. These plates are slipped into

a slot in the base of the hammer housing and receive the blow of the ram. The wood striking block or cushion is set into the heavy cast-iron follower on the pile and projects up into the socket of the hammer housing so that the McDermid base plate rests directly on the wood block. These wood blocks are made about 20 ins. long, 15 ins. in diameter at the center, and are hewed to about 12 ins. at top and bottom to enter respectively the hammer housing and the follower.

In driving through hard clay layers, or when the piling is bound slightly by crimps in the interlock, the blows of such a hammer may run as many as 30 to 60 to the inch of penetration on such driving. In hard driving, one or two fresh blocks per 30-ft. pile are often required. The time consumed in stopping and changing blocks is from two to five minutes, provided the block is not badly split and wedged in. It is necessary to watch the failure of these blocks closely, as with a crushed or broomed block the efficiency of the hammer is very low. Therefore the blocks are removed as soon as they show signs of failure. The crushing usually takes place toward the middle of the length of the block, making a hot, steaming pulp of the tough oak or maple fiber for a length of 3 to 6 ins. Partially seasoned swamp oak, rock maple and blue gum have given the writer the best service.

The form of cast-iron follower used with steel piling, and shown in Fig. 4, was designed by the writer, and patterns are owned by the Vulcan Iron Works, Chicago, Ill., and the Jarvis Engine & Machine Works, Lansing, Mich. Fig. 5 shows a steel pile being driven, fitted with the cast-iron follower and the spindle-shaped follower block above described. Flat-base followers are sometimes used, but do not hold the steel pile in position.

Process of Driving.—In driving steel sheet piling, if the alternate sections are light and heavy (that is, the heavy piles having double webs or double "Z" bars), drive first a heavy section. Go slowly and take great care to have the initial pile plumb and exactly in position. Then interlock a light section with the first one driven. On account of time consumed in cutting off steel sheeting weighing 30 lbs. to 54 lbs. per sq. ft., it is always desirable to back the driver away from the work. In close quarters approaching a wall, or in the end of a deep cut for a core wall, for instance, this is not always practicable. In starting small cofferdams, as for piers or foundations on buildings where close adherence to the line is required, one of the manufacturers of piling recommends that temporary piles about 4 ft. long be driven and taken out one at a time, and the long pieces of piling substituted, thus insuring starting correctly with the long piling.

Borings in casings are made along the proposed line of steel sheeting at say 25-ft. intervals, and the steel ordered to length accordingly. Except when encountering rock, boulders or extremely tenacious hardpan, the piles can usually be driven to a fairly uniform top level. When the objective foundation soil or rock bottom is in an eroded river valley which has again been refilled with drift the hard bottom will frequently be covered with a generous number

of boulders which have dropped out of the eroded material because too heavy to be washed down stream. This boulder stratum is, of course, quite irregular and not so desirable a material in which to terminate sheet piling as a good clay or slightly disintegrated rock

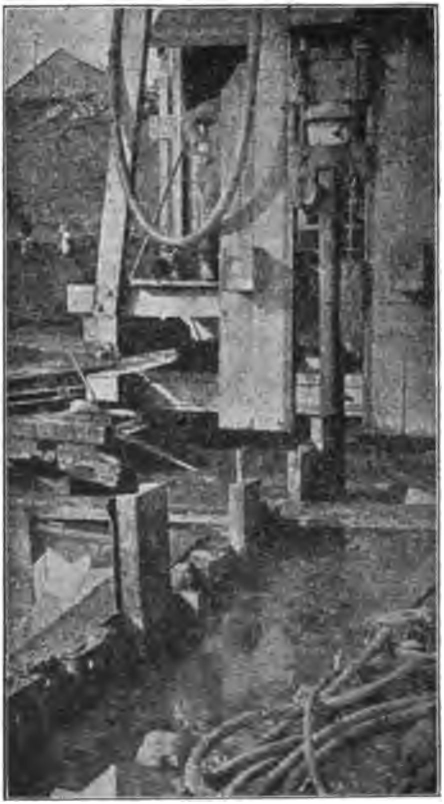


Fig. 5.—View Showing Arrangement for Driving Steel Sheet Piles. (A) Bottom of Steam Hammer; (B) Wooden Block; (C) Cast Iron Follower; (D) Steel Pile.

covering sound bedrock. Often too sound bedrock is deeply channeled and filled with pot holes, so that piling may need some cutting if it cannot be allowed to extend above grade, as into concrete.

The process of cutting steel piling by means of the electric arc was employed on the construction of the foundations for the New Hoffman House, Broadway and 25th St., New York City. The cost of cutting steel piling with current at 10 cts. per kw. and the attendant at 50 cts. per hour, is stated to be as follows per foot of piling cut:

Cost of current	$2.56
Labor	0.40
Total	$2.96

This is rather high, and the hack-saw would probably be cheaper. However, with current at say 3 cts. per kw.-hour the cost per foot would be but $1.17. Even at this rate, with labor competent to use a hack-saw at 25 cts. per hour, the saw would be the cheaper. The current used was at 50 volts, which was stated to be more satisfactory than either 25 or 105 volts. Tests showed 650 amperes consumed at the arc, which at 50 volts equals about 32 kw.

Boulders.—In passing a line of steel sheeting around a boulder of large size, special angle or bent piling sections are desirable to make the departure from and return to the line as planned. Some of the types of sheeting, like the Quimby or the United States, adapt themselves readily to such changes of alignment without using special pieces. Bending a ⅜-in. or ½-in. web longitudinally to short radius in the field is not an easy matter. When using rigid non-reversible interlocked piling in quicksand, and on work of such character that close water-tightness is required, special corner pieces should be kept on hand for emergencies. In some soils it may be permissible at times to turn corners by driving outside the interlock and tight against a projecting flange, placing the new piling at any angle required. Sometimes it may be feasible to fill gaps and make closures with specially prepared squared wood piles, with points beveled to make the wood piling hug the steel.

In hard driving among stones, only a type of piling of great stiffness laterally and with perfect interlocking features will insure success. On such work there must be no alternate unstiffened sections of piling. The interlock must be perfect and confining, difficult to open up and permit the escape of the inside member. Even with the heaviest and most confining type of interlocked piling now on the market in this country, this opening of interlock will sometimes occur when boulders are encountered. Small boulders in gravelly soils are usually displaced without trouble. Sometimes the aid of a water jet is a help. Usually steel piling will drive easily enough in ordinary soils without a jet. In hard clays a jet is not of much assistance and is very slow. Obviously it is not often required to drive steel sheeting far into hard clays.

In driving four lines of steel piling across the valley of the Muskegon River in Mecosta and Newaygo counties, Michigan, the borings showed "floating" masses of clay hardpan sometimes several hundred feet across, and from 1 ft. to 12 ft. thick. Below was quicksand before reaching a bed of hardpan continuous across the valley at a depth of about 30 ft. Hence the necessity for driving

through the floating hardpan. (See Fig. 6.) The hardpan in question consisted of about 70% of bluish clay and 30% of sharp sand, well mixed and compacted by water deposition and pressure, to the texture of frozen soil. In this hardpan were stones from gravel up to boulders of 5 tons weight. This material cost $3 per cu. yd. to trench, and angular fragments would lie for months in water moving with a velocity of 5 ft. per second without material erosion or change in form. This was at the Big Rapids dam of the Grand Rapids & Muskegon Power Co., in 1905. Lubricating the piling with grease before driving, and with a stream of water under pressure when driving, seemed to be of no special aid in the hardpan mentioned.

On the work at the Big Rapids Dam, above mentioned, the single-channel Friestedt piling frequently buckled and recourse was then had to double Z-bar Friestedt sections entirely. This piling with two Z-bars on all pieces weighs about 54 lbs. per sq. ft., and to reduce the weight the writer has had a single Z-bar riveted to every channel instead of using double Z-bar channels exclusively or

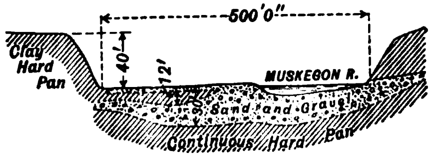


Fig. 6.—Cross Section of Muskegon River at Big Rapids Dam.

alternating with plain channels. The single Z-bar to every channel permits always having the free or uninterlocked edge of the pile being driven stiffened by a Z-bar. On this type, shown at No. 3 in Fig. 3, the writer has obtained a patent and has used over 1,000 tons with satisfactory results. Nearly all of this was driven into hard soils. On the Muskegon River work one carload was used of a special rolled type of piling having less radius of gyration than the built-up types above mentioned. Of this piling fully one-half buckled; it was thrown away and replaced with the other type.

Pulling Piling.—The manufacturers of steel piling place much stress on the ability to pull up the piles, but in his experience in hard soils the writer has never been able to get jacks enough on a piece of steel piling driven 12 ft. in the ground to pull it out. In soft river mud and silt, pulling with heavy tackle can be done. Probably a hammer striking upward blows in the manner similar to that used in pulling pipe casings from test bore holes would be operative except in cases of badly crimped and bent piles. [Note.—Steel piles can be pulled with stump pullers, as described in the section on Timberwork.]

Cost of Piling.—In lots of 500 tons, Friestedt steel piling sold in 1904 and 1905 at $1.93 per 100 lbs. on cars at the mill; this on alternate double Z-bar and channel and plain channel type. In

May, 1906, this type sold at \$2.03, and \$2.23 with a Z-bar on every channel, the additional price being on account of extra handling when every piece has to be riveted. The plain channels require only a 1-in. hole punched in the end for lifting.

The cost of driving per lin. ft. of piling 13¼ ins. net width, with a steam hammer, on the Muskegon River work above mentioned ran from 7¼ cts. to 20 cts. per sq. ft. in place; labor at 20 cts. per hour; foreman, 25 cts. The 7¼ cts. cost was on land in sand and gravel with some clay strata; piling 20 to 40 ft. long. The average amount of piling driven per hour in fairly good ground is 40 to 50 lin. ft., or 400 to 500 lin. ft. per day of 10 hours, including the time of moving the pile driver. In general the cost per sq. ft. for driving steel sheeting is 25% less than for driving wood.

Splicing Piling.—The longest single lengths driven on the writer's work was 44 ft., but spliced lengths up to 58 ft. have been successfully used. In doing spliced work it is not necessary actually to bolt or rivet the splices, the procedure being to use two lengths so as to break joints in the interlock. For 58-ft. piling, suppose we use 36-ft. and 22-ft. lengths: First drive the 36-ft. piece down, then move back and drive a 24-ft. pile down within a foot of the top of the 36-ft. piece; now move forward and set a second 22-ft. piece on top of the first 36-ft. piece and drive both down to full depth. Now move back past the 24-ft. pile and drive a 36-ft. piece in No. 3 position; then a 32-ft. piece on top of the 24-ft. piece. By moving back and forth so as not to lose the interlock below ground only two different lengths are required.

SUPPLEMENTARY DATA.

In addition to the cost given above in the original paper the author furnishes us some figures of the comparative cost of operating pile drivers by electric hoist and by steam hoist, and also further figures of the cost of sheet pile driving. These figures we give below.

Cost of Operating Pile-Drivers.—The following figures show the relative cost of operating two 2,000-lb. drop-hammer pile-drivers, one equipped with electric hoist and the other with steam hoist. These drivers had 38-ft. leads and worked side by side under the same conditions on round piling in sand and clay:

DRIVER WITH ELECTRIC HOIST.

One foreman, at \$3	\$ 3.00
Six helpers, at \$2	12.00
One team delivering at ½ day at \$4	2.00
Interest on investment at 5% (100 days' service)	1.00
Depreciation	1.00
Superintendence and engineering	2.00
Power	2.00
Total	\$23.00

In this driver the hammer was returned in the leads at a speed of 250 ft. per minute

DRIVER WITH STEAM HOIST.

One foreman, at $3	$ 3.00
Five helpers, at $2	10.00
One engineer, at $2.25	2.25
One fireman, at $1.75	1.75
One team delivering at ½ day at $4	2.00
Interest on investment at 5% (100 days' service)	1.00
Depreciation	1.00
Superintendence and engineering	2.00
Fuel, ½ ton coal, at $4	2.00
Total	$25.00

•In this driver the hammer was returned in the leads at a speed of 360 ft. per minute.

It will be noted that the electric hoist used was of considerably slower rope speed than was the steam hoist. Mr. Fargo notes that had the speed of the electric hoist been as great as that of the steam hoist it would have shown a lower cost record per lineal foot of piling driven on account of one less man at lower pay operating it. He states that any ordinarily bright man can be taught to operate an electric hoist in a day's time, but that a steam rig takes two men of more experience.

Cost of Driving Steel Sheeting with Steam Hammer.—The following figures show the cost per lineal foot of driving steel sheet piling in clay and sand, using a Vulcan steam hammer, with a 4,500-lb. ram and a total weight on the pile of 10,000 lbs. The driver had 55-ft. leads. The figures are for a 10-hour working day.

COST OF OPERATING DRIVER.

One foreman, at $3	$ 3.00
Four helpers, at $2	8.00
One engineer, at $2.50	2.50
One fireman, at $1.75	1.75
One team delivering at ½ day at $4	2.00
Interest on investment at 5% (100 days' service)	2.50
Depreciation	2.00
Superintendence and engineering	2.00
Fuel, 1 ton coal, at $4	4.00
Total	$27.25

The steel piling, consisting of one 15-in. channel and one special Z-bar as shown in sketch 3, Fig. 1, weighed 38 lbs. per lin. ft. and cost delivered 2.385 cts. per lb. The record for 16 days' driving, 8 days of fairly difficult work in strong soil and 8 days of fairly easy driving in sandy soil, was 6,400 lin. ft., or 400 lin. ft., or 15,200 lbs. per day. We can now summarize as follows:

Item.	Per day.	Per lin. ft.
15,200 lbs., at 2.385c	$362.52	$0.9063
Unloading from cars, at ½c per lb.	76.00	0.1900
Operating steam hammer	27.25	0.0682
Total	$465.77	$1.1645

Cost of Cleaning Steel by Sand Blast and Painting by Compressed Air.—Dr. De Witt C. Webb gives the following:

At the U. S. Naval Station, Key West, Fla., are two large steel coal sheds whose vertical side walls are composed of ¼-in. steel plates, and are from 16 to 20 ft. high. The action of heat and impurities in the coal, combined with that of the large quantities of salt water used for extinguishing spontaneous combustion fires rapidly corrodes the interior steel work and necessitates its thorough cleaning and painting every time the sheds are emptied.

Shortly after the writer was detailed to this station his attention was attracted to this subject, and he concluded that the use of a portable sand blast cleaning and spray painting outfit would be very advantageous in point of efficiency and time as well as cost. This idea meeting with the approval of the Bureau of Yards and Docks, the following outfit was purchased, at a cost of $2,090, delivered at the naval station:

1 horizontal gasoline engine, about 20 hp.

1 air compressor, capacity about 90 ft. of free air per minute compressed to a pressure of 30 lbs. per sq. in. in one stage, belt connected to engine.

1 rotary circulating pump, belt connected to engine.

1 galvanized steel water tank.

1 air receiver, 18 x 54 ins.

(The above apparatus was all mounted on a steel framed wagon with wooden housing.)

2 sand blast machines, capacity 2 cu. ft. of sand each.

2 paint spraying machines, one a hand machine of ⅔ gal. capacity for one operator, the other of 10 gals. capacity for two operators.

100 lin. ft. of sand blast hose.

200 lin. ft. of pneumatic hose for sand blast machines.

400 lin. ft. of pneumatic hose for painting machines.

100 lin. ft. of air and paint hose for painting machines.

4 khaki helmets, with mica-covered openings for the eyes.

200 lin. ft. of 2-in. galvanized iron pipe.

Previously to the delivery of this material shed "A" had been emptied of coal and the work of cleaning the inside surface of the wall plates was begun by hand in the usual manner. About 7,000 sq. ft. out of a total of 9,000 were thus cleaned at a cost of slightly over 4 cts. per sq. ft. On the arrival of the sand blast outfit the hand work was stopped and after a short preliminary trial the machine cleaning was started. The work proceeded rather slowly until the men became accustomed to it, yet the 2,000 sq. ft. of previously untouched surface was thoroughly cleaned and the 7,000 sq. ft. of hand cleaning was all gone over and much improved at a

total cost for labor of $97.68 and for gasoline of $16.15. The force consisted of the following:

	Per day.
1 engine tender	$ 3.04
1 helper (in charge of the work and tending machines)	2.24
2 laborers on machines, at $1.76 each	3.52
1 laborer drying sand, filling machines, etc.	1.76
Total	$10.56

From 10 to 15 gals. of gasoline were required per day of 8 hours (costing 19 cts. per gal. here).

For the painting the coal tar paint originated by Civil Engineer A. C. Cunningham, U. S. N., was used. This paint was prepared with the following proportions (by volume): Coal tar, 4 parts; kerosene oil, 1; Portland cement, 1.

The Portland cement was first well stirred into the kerosene oil, forming a creamy mixture; this mixture was then carefully stirred into the coal tar. It was freshly mixed as needed and kept well stirred. The cost of this paint at Key West is about 15 cts. per gal. It was found not to be so well suited to the pneumatic spraying machine as oil paint, but worked very well; though, of course, the machine used considerably more than hand work. In all, on this shed, 64½ gals. of paint were required for 9,000 sq. ft., or about 1 gal. to 140 sq. ft. The force used in painting was the same as in cleaning, with the addition of a laborer, who followed up the painters with a long handled brush and spread the paint uniformly. The cost of painting this shed was: For labor, $28.16; for gasoline, $3.80.

On shed "B" a total area of 12,500 sq. ft. was cleaned and painted. This steel work was covered with a scale nearly ⅛ in. thick and was deeply pitted. The scale and rust were very tough and extremely hard to remove. On this work it was found economical to keep men ahead of the sand blast with sledges, loosening and shaking off as much of the scale as possible. The labor cost of the whole work on this shed (cleaning and painting) was $460, including the cost of moving, setting up and removing. Gasoline cost $81. A total of 86 gallons of coal tar paint was used, covering about 145 sq. ft. per gal. Total cost of labor, fuel and paint, $553.90, or 4.4 cts. per sq. ft. It is impossible to separate the cost of cleaning and painting on this work, as only small areas are painted at one time, the painting being done by one operator, the other working the sand blast. This was done in order to expose the cleaned steel to the atmosphere for as short a time as possible.

A fine silica sand was used, that being the only kind available except coral sand, which was tried, but found to be too soft. A coarse sand would probably have been more effective. The sand was all saved, dried and re-used several times. About ½ cu. yd. of fresh sand was required daily. The sand must be kept perfectly dry for this purpose, and there are patent sand driers manufactured. Very good results were obtained on this work, however, by the use

of a sheet of boiler plate set up on bricks with a wood fire underneath.

No claims are made of extreme economy in the above work. The extremely thick and tough scale to be removed, the high fuel and labor cost of compressing air simply for this work, and (probably) the lack of the best kind of sand for the purpose, combined to make the work expensive. With these drawbacks it was, however, considerably cheaper than hand work and, what is more important, the cleaning was much more effective and thorough than could possibly have been done by hand.

SECTION XIV.

ENGINEERING AND SURVEYS.

Cost of Engineering.—When work is done by contract, engineering costs from 3 to 10% of the total cost of construction. This includes surveys, plans, estimates and inspection during construction. The major part of this cost is usually the supervision and inspection of the contractor's work. Hence, if the job is small, and if the work drags, the cost of engineering will approach, or even exceed, 10%.

Throughout this book are given actual records of the cost of engineering, for which consult the index under "Engineering."

Engineering Charges For Services.*—The following information as to the minimum charges for engineers' services in Iowa, was collected by the Secretary of the Iowa Engineering Society and printed in the Proceedings of the 21st annual meeting of the society:

Expert Services:

One day	$50.00
Each additional day	25.00
Expert testimony, per day	50.00
Services of hydraulic or sanitary engineer in examinations, reports, estimates, per day	25.00
Construction engineer's and detail work, per day	10.00
Special rates for corps of engineers and inspectors to take charge of work according to importance and degree of skill required.	

City Surveys and General City Work:

Field and office work, per day of 8 hours	8.00
First assistant, per day of 8 hours	4.00
Second assistant, per day of 8 hours	2.40
Time taken going to and returning from survey to be included in above 8 hours. Not less than half a day to be charged.	
Surveys of single city lots, not less than	6.00
Unless previous surveys have been made of adjoining lots in same plan, then	5.00
No description to be drawn for less than	1.00
No charge to be less than	1.00

Laying out of additions of not less than 20 acres, $1.00 per lot, to include working plats and plat for record; but owner must furnish the design of plat or else pay engineer for time consumed in determining method of division.

All expenses, such as railway fare, hotel expenses, conveyances of any kind, posts, monuments, are to be charged for as extra.

County Land Surveys by County Surveyor:

Fees prescribed by law. Surveyor, 50 cts. per hour; assistants, 20 cts. per hour. All expenses are allowed and charged for as extra.

**Engineering-Contracting*, Oct. 20, 1909.

There seems to be doubt as to what constitutes a day for a County Surveyor, but, as the law prescribes 8 hours in county road work and various other service, it is safe to say that 8 hours is a legal day, and it has been held so in the courts.

Cost of Engineering on City Work.—During the years 1901 to 1906, some $2,133,000 were spent for sewers, waterworks and pavements in Salt Lake City, Utah, and the engineering cost 4.8% of this amount.

Cost of Engineering in Reservoir Construction.*—On the East Branch, the Carmel, the Titicus and the Jerome Park reservoirs, for New York City, the cost of engineering averaged 10% of the construction cost of $9,532,000. This engineering includes all surveys, test borings, designs and inspection. However, 10% is a very high percentage of cost for work of such magnitude.

Rations for Men Camping.—In the rules for a railway location prepared by McHenry for surveying parties on the Northern Pacific Ry., the following list of rations and supplies is given: The food is sufficient to support 14 men at least 30 days.

400 lbs. flour.
50 lbs. buckwheat.
40 lbs. oatmeal.
30 lbs. cornmeal.
25 lbs. rice.
10 lbs. tapioca.
10 lbs. sago.
10 lbs. barley.
10 lbs. cornstarch.
10 lbs. baking powder.
3 lbs. soda.
12 packages yeast cakes.
150 lbs. sugar.
20 lbs. salt.
50 lbs. coffee.
10 lbs. tea.
5 gals. syrup.
1 gal. vinegar.
400 lbs. potatoes.
50 lbs. beans.
20 lbs. onions.
2 cases (24 qts.) tomato.
2 cases corn.
1 case peas.
1 case pears.
1 case cherries.
2 cases peaches.
1 case milk.
1 case coal oil.
2 lbs. mustard.
1 lb. ground pepper.
½ lb. ginger.
½ lb. cinnamon.
¼ lb. allspice.
¼ lb. nutmegs.
1 bottle lemon extract.
1 bottle vanilla extract.
6 bottles pickles.
6 bottles catsup.
8 bottles Worcester sauce.
100 lbs. ham.
100 lbs. bacon.
25 lbs. dried beef.
25 lbs. codfish.
40 lbs. lard.
25 lbs. cheese.
60 lbs. butter.
1 case cornbeef.
50 lbs. dried apples.
50 lbs. dried peaches.
50 lbs. dried prunes.
10 lbs. dried currants.
1 box raisins.
1 box crackers.
1 box macaroni.
1 box soap.
12 boxes matches.
1 box candles.
2 lbs. lye.
10 lbs. sal-soda.

The total net weight of food in this list is about 2,100 lbs., or about 5 lbs. of food per man per day, on the basis of 420 man-days. This is certainly ample. In fact men can live on much less if concentrated food that swells on cooking is used. The following is a

Engineering-Contracting, July 8, 1905.

list used by the author on a 30-day camping expedition where every superfluous pound of weight was cut out:

	One man. 30 days.	One man. 1 day.
Flour	25 lbs.	0.83 lb.
Oatmeal	8 lbs.	0.27 lb.
Rice	4 lbs.	0.14 lb.
Beans (dried)	8 lbs.	0.27 lb.
Sugar	12 lbs.	0.40 lb.
Salt	1 lb.	0.03 lb.
Butter	2 lbs.	0.07 lb.
Bacon	10 lbs.	0.33 lb.
Baking powder	1 lb.	0.03 lb.
Coffee	2 lbs.	0.07 lb.
Tea	¼ lb.	0.01 lb.
Dried prunes	2 lbs.	0.07 lb.
Pepper	¼ lb.	0.01 lb.
Condensed milk	3 cans	0.10 lb.
Total	79 lbs.	2.63 lbs.

This list furnishes 0.23 lb. nitrogenous food, 0.30 lb. fat., and 1.39 lbs. starch and sugar per man per day. Dr. Pavy (Encyclopedia Britannica) states that a laborer requires daily 0.25 lb. nitrogenous food, 0.10 lb. fat, and 1.18 lbs. starch and sugar (carbohydrates). If the trip is to be a long one, 1½ ozs. of juice of lime per man per day should be taken to prevent scurvy, unless potatoes can be carried along.

F. W. D. Holbrook, in Jour. Assoc. Eng. Soc., 1883, p. 180, gives the following rations for 20 men for 12 days, where all food has to be packed on the backs of men (1,400 lbs. of food for 240 man-days):

12 bottles prepared mustard.
25 lbs. butter.
170 lbs. ham.
75 lbs. canned cornbeef.
50 lbs. mess pork.
300 lbs. flour.
25 lbs. dried apples.
25 lbs. dried peaches.
50 lbs. prunes.
25 lbs. raisins.
10 lbs. currants.
12 lbs. baking powder.
10 lbs. salt.
100 lbs. granulated sugar.
50 lbs. brown sugar for syrup.
10 lbs. tea.
15 lbs. coffee.
70 lbs. beans.
25 lbs. rice.
½ lb. ground pepper.
½ lb. ground ginger.
1 lb. ground cinnamon.
12 lbs. soap.
15 lbs. candles.
6 boxes matches (300 in box).

The U. S. Geological Survey ration list is as follows for 1 man for 100 days:

100 lbs. fresh meat, including fish and poultry.
50 lbs. cured meat, canned meat, or cheese.
15 lbs. lard.
80 lbs. flour, bread or crackers.
15 lbs. cornmeal, cereals, macaroni, sago or cornstarch.
5 lbs. baking powder or yeast cakes.
40 lbs. sugar.
1 gal. molasses.
12 lbs. coffee.
2 lbs. tea or cocoa.
10 cans condensed milk, or 50 qts. fresh milk.
10 lbs. butter.
20 lbs. dried fruit, or 100 lbs. fresh fruit.
20 lbs. rice or beans.
100 lbs. potatoes or other fresh vegetables.
30 cans of vegetables or fruit.
4 ozs. spices.
4 ozs. flavoring extracts.
8 ozs. pepper or mustard.
3 qts. pickles.
1 qt. vinegar.
4 lbs. salt.

Eggs may be substituted for fresh meat in the ratio of 8 eggs for 1 lb. of meat. Fresh meat and cured meat may be interchanged on the basis of 5 lbs. of fresh for 2 lbs. of cured. Dried vegetables may be substituted for fresh vegetables in the ratio of 3 lbs. of fresh for 1 lb. of dried.

This ration weighs 5.3 lbs. per day per man, and it costs about 50 cts. per day per man. The list was based originally on the U. S. army ration, but has received some modifications dictated by experience.

Cost of Rations, U. S. Reclamation Service.*—From the annual report of the U. S. Reclamation Service for 1904-5, the cost of rations for the employes of that body, engaged on several of the reclamation projects, were from 40 to 80 cts. per man per day, averaging about 55 cts.

Equipment For and Cost of Railroad Surveys.—Mr. F. Lavis in his admirable book on "Railroad Location, Surveys and Estimates," has given valuable information on railway surveying and estimating, from which the following data have been abstracted:

The following is a list of the camp outfit:

1 office tent with fly, 14 x 16 ft.
3 tents, 14 x 16 ft.
1 cook tent, 16 x 20 ft.
3 drafting and office tables.
6 camp chairs.
Map chest with necessary stationery, paper, etc.

Engineering-Contracting, Oct. 24, 1906.

Dining Table.

3 dozen agate ware dinner plates.
3 dozen agate ware cups.
2 dozen agate ware saucers.
2½ dozen steel knives.
2½ dozen steel forks.
2½ dozen German silver teaspoons.
1½ dozen German silver dessert spoons.
1 dozen German silver tablespoons.
½ dozen tin salt boxes.
½ dozen tin pepper boxes.
¼ dozen round agate ware pans, 2 qt.
½ dozen round agate ware pans, 1 qt.
1 dozen round agate ware pans, 1 pt.
1 carving knife and fork.
7 yds. oilcloth, 48 ins. wide.
3 standard trestles.
5 boards, 12 by 1½ ins. by 18 ft. (dressed).

Cooking Utensils.

1 No. 8, 6-hole, wrought-iron range.
1 tea-kettle.
1 large cast-iron pot.
1 small cast-iron pot.
2 large frying pans.
1 gal. teapot.
4 dripping pans.
6 baking tins for bread.
12 tin pie plates.
2 butcher knives.
1 steel.
2 large meat forks.
1 chopping knife.
1 meat saw.
2 large iron spoons.
1 soup ladle.
1 cake turner.
1 flour sieve.
1 colander.
1 5-gal. tin dishpan.
1 5-gal. tin bread pan with cover.
1 small frying pan.
2 griddles.
4 tin pans with covers, 1 gal. each.
2 stewpans.
1 3-gal. coffeepot.
1 chopping bowl.
1 bread board.
1 rolling-pin.
1 biscuit cutter.
1 nutmeg grater.
1 coffee mill.
1 spring balance.
6 galvanized iron buckets.
6 tin dippers (one for each tent and two in cook tent).
2 can openers.
1 corkscrew.
1 broom.
1 scrubbing brush.
1 alarm clock.
1 table (same as drafting tables).

Miscellaneous.

½ dozen Dietz lanterns.
3 large tin lamps (central-draft, round wicks).
2 large galvanized-iron washtubs.
1 washboard.
4 Sibley stoves (4 lengths of pipe with dampers, 12 lengths of plain pipe).
2 water kegs, 2 gals. each.
6 washbasins.

Tools.

1 grindstone and fittings.
1 monkey wrench.
1 pick.
2 shovels.
1 short crowbar.
1 hand-saw.
1 cross-cut saw.
2 hand-axes.
4 chopping-axes.
½ dozen axe handles.
1 bundle sail twine.
½ dozen sail needles.
1 sail palm.
10 assorted sizes wire nails.
100 ft. manila rope, ¾-in.

LUNCH BOX.

2 dozen agate ware dinner plates.
2 dozen agate ware saucers.
1½ dozen steel knives.
1½ dozen steel forks.
1½ dozen German silver teaspoons.
1½ dozen German silver dessert spoons.
1 2-gal. coffeepot.

Each locating party was organized as follows:

Locating engineer	$150 to $175
Assistant locating engineer	115 to 125
Transitman	90 to 100
Leveler	80 to 90
Draftsman	80 to 95
Topographers, two*	80 to 90
Rodman	50
Head chainman	50
Rear chainman	40
Tapeman, two*	30
Back flagman	30
Stake marker	30
Axemen (three to five as necessary)	25 to 30
Cook	50
Cook's helper	20
Double teams and driver, furnish their own feed, driver board in camp	65 to 90

*One of the topographers assisted by two tapemen, with a transit determined land lines and drainage areas.

Each man was supplied by the company with subsistence when in camp, but was required to provide himself with an army cot and sufficient bedding, and advised to provide a substantial canvas covering for the latter, an ordinary wagon cover, costing from $3 to $5, being the most easily obtainable and most satisfactory.

Most of the lines ran through a rather badly broken up, rolling country (Indian Territory, Oklahoma and Texas), with short cross-drainage, about 75% being wooded. Topography was taken 300 ft. on each side of the line, a hand level and rod being used, distances out were placed, and 5-ft. contours located and sketched. The average amount of grading was 100,000 cu. yds. per mile;; maximum grade, 0.5%; maximum curve, 2°. The cost of the surveys was as follows for 563 miles of preliminary and 188 miles of located lines:

PRELIMINARY LINES.

	Party No. 1. July 5th to October 1st.	Party No. 2. July 22d to October 20th.	Party No. 3. Aug. 1st to Nov. 19th.	Party No. 4. Sept. 21st to October 21st.
	87 days.	90 days.	111 days.	30 days.
Miles run and topography taken.	145.8	166.3	164.1	23.2
Miles run, no topography taken..	39.3	....	16.0	3.6
Total miles preliminary run.....	185.1	166.3	180.1	31.8
Total number payroll days......	1380	1323	2033	635
Average daily number of men....	15.9	14.7	18.3	21.2
Average miles per day per party.	2.12	1.85	1.62	1.06
Average daily cost, subsistence per man	$0.37	$0.49	$0.38	$0.58
Average daily pay per man....	1.81	2.03	1.66	1.66
Daily cost for teams............	6.00	6.22	6.92	12.87
Contingencies	88.48	112.95	91.84	125.73
Daily cost of party.............	41.72	44.48	45.57	64.61
Cost per mile..................	19.61	24.07	28.08	60.95

LOCATED LINES.

	Party No. 1.	Party No. 2.	Party No. 3.	Parties Nos. 2 and 3 Combined.	Party No. 4.
	65 days.	37 days.	8 days.	48 days.	66 days.
Miles located	56.0	37.8	7.6	42.6	39.2
Total number payroll days	1400	709	151	1498	1283
Average daily number of men	21.5	19.0	19.0	31.2	19.4
Average miles per day per party	0.86	1.02	0.95	0.89	0.59
Average daily cost subsistence	$0.37	$0.39	$0.39	$0.40	$0.45
Average daily pay per man	1.72	1.61	1.61	1.71	1.60
Daily cost for teams...	6.69	5.75	5.39	10.33	6.76
Contingencies	143.36	46.76	15.70	196.00	133.84
Daily cost of party.....	53.90	45.22	45.12	80.29	48.54
Cost per mile..........	62.57	44.33	47.50	90.47	81.72

The preliminary lines run by Party No. 1 were over a severe country, involving the heaviest construction work on the whole line. Party No. 3 also had much difficulty in getting a grade between certain points. Party No. 2 had the lightest country. Party No. 4 worked only a short time and the cost of moving a long distance from other work is included. It is probable that the cost of work done by this party was really about 60% more than the others per mile, instead of 100% more.

On the locating work, Party No. 1 had an expensive sounding party consisting of a man in charge, 4 or 5 laborers and a team.

Parties Nos. 2 and 3 were combined, after each had run a short distance of located line separately, which increased the unit cost of the located line, as shown.

The total cost of 188 miles of located line was $192 per mile of located line, and this includes the cost of running the preliminary lines.

Cost of 2,000 Miles of Railway Surveys.—In a paper by Mr. W. S. McFetridge, published in Trans. Am. Soc. C. E., 1909, and reprinted in *Engineering-Contracting*, May 19, 1909, is given a very complete description of the methods of making 1,400 miles of preliminary and 600 miles of location surveys. The following is a very brief summary of the cost.

Field parties were made up as follows:

	Monthly Salary.
Assistant engineer in charge	$125 to $150
Transitman	85 to 100
Levelman	75
Rodman	65
Head chainman	50
Rear chainman	45
Rear flagman	40
Stakeman	35
Axeman (from two to five)	30
Topographer	65
Tapemen (two)	45
Draftsman (part time)	60

Camp outfits were not used. The parties boarded at houses along the line. This was often a disadvantage, on account of difficulty in getting quarters, especially for a full corps; but, on the other hand, the party could frequently make its headquarters at some town and drive to and from the work, so that probably this method served just as well as furnishing camp outfits.

It may appear to some that there was much unnecessary location and running of preliminary lines, but in rough country like this, and on work of this magnitude (in 220 miles of this line were 21 tunnels, the longest being 4,000 ft., 5 viaducts from 400 to 1,000 ft. long, and more than 100 ft. in height, besides numerous other bridges), it is time and money well spent. In no other way can the exact data be gotten, and it leaves no question as to the available routes and the grades obtainable. The topography was taken (on practically all lines) accurately by using a metallic cloth tape for distances and a hand-level for elevations. Only in this way can one get a projected location to correspond closely with the actual one. The topography was ordinarily taken for 300 ft. on each side of the center line; at particularly difficult summits or similar places a strip from 1,000 to 2,000 ft. wide was often shown. The lines were plotted to a scale of 200 ft. to 1 in. The topography was plotted in the field. A hollow drawing-board, 18 x 24 ins. was used. The sheet in use was tacked to the board, and the additional sheets were carried inside. A strap around the shoulders of the topographer served to carry the board, and formed a support while plotting (Wellington's method).

TABLE I.

Company (1)	Amount Spent. (2)	Miles of Survey. Prelimi-nary. (3)	Location. (4)	Total. (5)	Av. cost per mile. (6)	Av. cost per mile of location. (7)
L. K. R. R.	$25,076.83	428.19	193.35	622.04	$40.31	$129.36
Z. M. & P.	19,812.77	509.03	105.23	614.26	32.25	188.28
B. & E. R. R.	20,466.68	241.75	113.70	355.45	57.58	180.00
P. B. & T. R. R.	6,651.98	84.56	38.17	122.73	54.20	174.28
B. & N. R. R.	19,249.94	162.51	151.29	313.80	61.34	127.23
Totals	$91,258.20	1,426.04	602.24	2,028.28	$45.00	$151.58

Cost.—The greatest number of miles of preliminary line run in one day by one party was 7, and of location, 4½. The location averaged slightly more than 1 mile per day per party, except on two lines, where it averaged ¾ mile. Stakes were set every 100 ft. on tangents, and every 50 ft. on curves. Special pains were taken with the instrument work and measurements, in order to avoid the chance of serious errors in the center line after construction commenced. The speed of location parties was usually limited by the amount of clearing that could be done, but the number of curves and the rough character of the ground were also large factors in limiting the speed.

Each party cost from $35 to $40 per day, being allowed all expenses in addition to salaries.

Table I gives the cost per mile of the completed surveys. It is to be noted that this is the total cost, and includes office rent, purchase of instruments and supplies, general expenses, all salaries, field expenses, and the preparation of final maps, plans, profiles, and estimates, with everything in readiness to make contracts for the line.

Column 7 gives the cost per mile of actual location, including preliminary lines. Columns 3 and 4 show that there were from 2 to 5 miles of preliminary lines run for each mile of location, except on one line. Table I also includes 302 miles of check levels, the cost being distributed among the various accounts. The data for the Parkersburg Bridge and Terminal line include surveys and soundings for the Ohio River Bridge. The cost per mile includes the topography on practically all lines, except one where it was taken only on the located lines.

The cost shown in Table I being the total charge against engineering from the inception of the project to the beginning of construction, contains a few items which might well be charged to other accounts than location. Instruments purchased could be a credit; some elaborate property surveys and bridge surveys could be charged to construction, but they probably are not large enough to have much effect on the cost per mile. If taken into account, they would reduce the cost.

A line run in midwinter may easily cost one-quarter more than if run during more favorable weather.

TABLE II.

	—Average Cost of One Mile.—		
Company—	Of preliminary.	Of location.	Of location including preliminary.
L. K. R. R.	$25	$ 74	$ 99
Z. M. & P. R. R.	23	79	102
B. & E. R. R.	35	105	140
B. & N. R. R.	31	94	125

The figures in Table II include all expenses, as in Table I.

Table I shows a large variation in the cost of surveys on different divisions, the cost varying from $128 to $188 per mile, with an average of $151. On the assumption that lines located for comparison or similar purposes should be included in the average, one-third

should be added to these amounts, as previously noted; the cost would then be as follows:

Low	$171 per mile
High	251 per mile
Average	202 per mile

Throwing out of the account the mileage of abandoned lines, branch lines, etc., and charging the entire cost to the main line, terminus to terminus, would give $\frac{\$91,258.20}{328} = \$278.23$ per mile, which would be rather expensive. This, however, is not a fair assumption, and should not be considered, because many miles of lines not needed to determine the main line were located for other reasons and purposes. Therefore, the plan of throwing out only duplications, for comparisons, as shown in the preceding paragraph, gives the correct average cost per mile for the development of the country, including actual comparative locations where needed. It should also be borne in mind that a large proportion of this duplication was necessary, owing to the laws of West Virginia, which require an actual line, located on the ground, and a complete map and profile of that line to be filed with the Secretary of State, and at the county seat, before a railroad company has any rights, of priority or otherwise, to that route or line. This required complete locations for all proposed branch lines, a large number of which were located, and also a complete location over any route for which it was desired to obtain rights. For these reasons, the lines located account for the excess of the mileage over the actual length of the main line.

On the basis of Table II, it may be assumed that, where the route has been previously determined within such narrow limits that the preliminary and location lines are of equal length, the surveys will cost from $100 to $140 per mile. This is borne out by the results on the Buckhannon and Northern line, where the location and preliminary lines were practically equal and the cost was $127 per mile.

These two statements may be combined and put in the following form:

To locate one mile, including an equal length of preliminary lines, cost from $100 to $140; average	$115
To locate one mile, final location, including from two to five times as great a length of preliminary lines, cost from $128 to $188; average	151
To locate one mile, final location, including from two to five times as great a length of preliminary lines, and one-third of a mile of location for comparison, cost from $171 to $251; average	202

A tabulation of the mileage of the Buckhannon and Northern line, with reference to the actual length of line to be built, and showing how the results agree with the averages deduced from Table I, is as follows, the Buckhannon and Northern line being used because the conditions there make it the best average of "all conditions" encountered on the various lines.

Total miles located		151.29
Miles of main line contracted for	80	
Miles of main line not contracted for	4	
Miles of connecting line located, but which may or may not be built, about	26	110.00
Making actual miles	110	
Leaving duplications, comparisons, etc.		41.29

110 miles cost $19,249.94 = $175 per mile.

Cost of a Railway Survey, Canada.*—The following data relate to a survey made in Canada in 1906 for the Grand Trunk Pacific Ry. The lines were run through gently rolling prairie country, with three rather difficult river crossings. The topography was taken 800 ft. on each side of the line, locating 5 ft. contours. The maximum grade was 0.4%, and the maximum curve was 4°. Some rather fast work was done in the survey, for on Oct. 10 12.46 miles of line was located in 8 hours and 20 minutes. An average of 8.4 miles per day was also made in 22 days worked. The organization of the party and wages paid were as follows:

	Per month.
Locating engineer	$ 175.00
Transitman	100.00
Levelman	75.00
Topographer	75.00
Draughtsman	75.00
Head flag	45.00
Level rodman	45.00
Head chainman	45.00
Rear chainman	30.00
Topog. chainman	30.00
Topog. rodman	30.00
Rear flagman	30.00
Stakeman	30.00
Axeman	30.00
Cook	60.00
Cookee	30.00
One saddle horse	30.00
Three teams at $100	300.00
Total	$1,235.00

The following is a record of the cost of the survey and the work accomplished:

	Preliminary. 24 Days.	Location. 60 Days.
Miles run and topography taken	175.3	308.0
Total miles location and alternative location	....	308.0
Total miles preliminary run	175.3	.....
Total number payroll days	384.0	960.0
Average daily number men	16.0	16.0
Average miles per day	7.3	5.13
Daily cost of subsistence per man	$ 0.41	$ 0.41
Average daily pay per man	1.85	1.85
Daily cost for teams	10.67	10.67
Contingencies	18.00	77.00
Daily cost of party	47.83	47.87
Cost per mile	6.55	9.32

*Engineering-Contracting, Feb. 19, 1908.

The survey was made under the direction of Mr. C. J. Seymour, Kansas City, Mo., to whom we are indebted for the above information.

Cost of Reconnaissance Survey for Railway in Alaska.*—Mr. Fred. Lavis is author of the following:

The following costs of a reconnaissance survey for railroad location in Alaska in the winter of 1906-7 were furnished the writer by Mr. H. R. Gabriel, Locating Engineer, Katalla, Alaska. The payroll was as follows:

	Per month.
Chief of party	$ 250
Transitman	125
Topographer	100
Draftsman	100
4 dog mushers	400
2 axemen	200
1 rodman	100
Cook	100
Total	$1,375

The total cost of the survey was $13,500, distributed as follows:

Salaries	$ 8,050
Subsistence	2,810
Cost of 22 dogs at $60 each	1,320
Feed for dogs	1,320
Total	$13,500

Average cost $50 per mile.

The survey covered a route 270 miles long between Fairbanks and Seward, Alaska, and was made between Jan. 1 and May 25, 1907. For a period of three weeks no work was done, the temperature ranging from 60° to 70° below zero, but work was carried on when the temperature was 36° below. The dogs were worked in four teams and on newly broken trails hauled 500 lbs. per team; they were fed on bacon, rice and fish which cost 40 cts. per day per dog.

The camping equipment was very light, consisting of one 10 x 12 ft. and two 14 x 16 ft. tents, two Yukon stoves and but very few dishes.

The average distance between camps was 10 miles, and but 4 or 5 days were spent in each camp.

The following is the list of rations allowed:

***Engineering-Contracting*, Dec. 9, 1908.

	Lbs.
Flour per man per day	1 to 1.25
Beans per man per day	0.25 to 0.50
Rice per man per day	0.12
Bacon per man per day	0.12 to 0.25
Ham per man per day	1.00
Dried fruit per man per day	0.20 to 0.25
Dried corn per man per day	0.10
Sugar per man per day	0.30
Butter per man per day	0.16
Salt per man per month	0.75
Pepper per man per month	0.05
Other spices in proportion to pepper.	
Tea per man per month	0.50
Coffee per man per month	0.67
Cocoa per man per month	0.33
Dried potatoes per man per day	0.08
Rolled oats per man per day	0.08
Corn meal per man per day	0.08
Canned milk (can) per man per day	0.16
Macaroni per man per day	0.14
Cheese per man per day	0.08
Lard per man per day	0.05
Crystal eggs per man per month	0.33

Baking powder 1.5 lbs. per 50 lbs. flour.
Yeast cakes, 12 men per month, 10 pkgs.
Soda, 12 men per month, 1 pkg. Sour dough bread was used.
Concentrated vinegar, 12 men 6 months, one 6-oz. bottle.
Mustard, 12 men 6 months, 4.5 lbs.
Olive oil, 12 men 1 month, 0.1 gal.
Beef tea, 12 men 1 month, 20 jars.

This reconnaissance was a stadia survey, all distances both vertical and horizontal being measured with the transit, no level was used; topography sufficient to make a rough projected location and fairly accurate profile where it varied from the main line run, was taken with a clinometer.

It will be noted that all the information necessary to make a fairly accurate projected location was obtained on this survey at a comparatively small cost. Its value lies somewhere between the ordinary reconnaissance and the so-called preliminary location which should properly be a preliminary survey.

A preliminary survey of this line if properly made would have given more accurate detailed information, but its cost would have been between $250 and $350 per mile according to statements of actual costs of preliminary surveys in Alaska, made by Messrs. Cryderman and Kyle in a paper read before the Pacific Northwest Society of Engineers early this year.

The stadia furnishes accurate (within the really necessary practical limits) information as to distance, direction and elevation, which can be obtained in no other way as cheaply, and without any one of which it is impossible to form any reliable estimate of the practicability of any line or its cost, the addition of a very limited amount of topography taken by an experienced topographer enables a projected location to be made which should be well within a close approximation of the final line,

In regard to the salaries given they seem too low. The transitman, topographer and draftsman were not paid any more than good men get in the older parts of the United States where conditions of existence are not so rigorous; without intending any reflection on the men composing the party, the writer believes that in these positions competent men would be worth at least 50% more than was paid on this survey.

Cost of Locating Two Railroad Lines in Michigan and Wisconsin.* One line was located from Traverse City to Elk Rapids and from Williamsburg to Petosky. The survey was begun Sept. 1, 1889, and finished May 1, 1890. The country was covered with heavy hardwood and hemlock timber and dense cedar swamps. The ground was alternately flat and very rough, in sections of 6 to 10 miles in length. About 25 miles of the 91 were located on the shores of small lakes bounded by steep bluffs which came down close to the shore, the latter being very irregular. The winter was a light one, except in February, when the snow was 3 ft. deep, which considerably reduced progress.

The following was the organization of the part, and the monthly cost of making the survey:

	Per month.
Chief of party	$ 100.00
Transitman	75.00
Leveler	100.00
Rodman	40.00
Chainman, head	40.00
Chainman, rear	30.00
Back flagman	30.00
4 axemen at $30	120.00
Cook	40.00
Cookee	15.00
Team and driver	90.00
½ time of Division Eng., at $125	62.50
Expense of camp	270.00
Total	$1,012.50

The survey occupied 8 months, making the total cost $8,100, which is equivalent to $89 per mile of located line, there being 91 miles located. The total number of miles of line run, including preliminary lines, was 250 miles. Stated otherwise, there were nearly 2 miles of preliminary line run to each mile of located line.

In all there were 208 working days, but, in moving and on account of bad weather, 20% of this time was lost, thus reducing the actual number of days worked to 188. The following was the amount of line run per day:

	Miles.
Total line per day (208 days)	1.20
Located line per day (208 days)	0.44
Total line per day (188 days)	1.33
Located line per day (188 days)	0.48

It will be noted that there were 14 men and a team of horses, and that the expense for food, etc., was $270 per month. Counting

Engineering-Contracting, January, 1906.

each horse as the equivalent of a man in expense of feeding, we have a daily expense of slightly less than 60 cts. per man per day for food. That is a liberal estimate for present conditions, but on the other hand, salaries and wages are somewhat higher now than they were 15 years ago.

Another line, 227 miles long, was run in November and December of 1891, for the Saginaw & Western R. R., from Sparta to Howard City. The country was in part very rough. The timber was principally very light, with some brush. The ground was generally covered with logs and stumps. Considerable of the line was in old pine choppings. No team was provided for carrying the men to and from the work. The following was the monthly payroll:

	Per month.
Assistant engineer	$125.00
Transitman	100.00
Leveler	100.00
Rodman	40.00
Chainman, head	45.00
Chainman, rear	30.00
Flagman	30.00
3 axemen	90.00
Cook	45.00
Total	$605.00

The party, which was composed of 11 men, was paid for 48 work days. The actual number of days worked, however, was 36, Sundays and rainy days accounting for the other 12. The party was in camp for 42 days; on the remaining 6 days they boarded and roomed at hotels. The total cost of the field work was $1,307.97, divided up as follows:

Payroll	$972.00
Supplies	167.77
Board and hotel bill	50.25
Axes, grindstone, etc.	16.00
Miscellaneous expenses	98.75

To the cost of the field work must be added the cost of the office work for maps, profiles and estimates. This amounted to $219.75, making the total cost of the survey $1,524.72. A total of 71.4 miles of line was run, of which 48.7 miles was preliminary line and 22.7 miles was located line. The actual number of days worked on the preliminary line was 25; actual number of days on located line was 11. The following table gives the average amount of line run per day worked:

	Stations.	Miles.
Preliminary line	102.8	1.947
Location	109	2.064
Average line per day	104.7	1.983
Average line per day out	78.5	1.486
Location line per (36 days)	33.3	0.634
Location per line (48 days) out	25	0.473

The cost of the survey per station and mile was as follows:

	Per station.	Per mile.
Field work	$1.09	$57.50
Office and field work	1.77	67.17

As was stated previously, the party was composed of 11 men and was in camp for 42 days. The total cost of food, supplies, etc., including the cook's wages for this time, amounted to $228.70. The cost per man per day for supplies only amounted to 36 cts.; including the wages of the cook, the cost per man per day was 49 cts.

Cost of a Railroad Re-Survey, Canada.*—In a paper read before the Ontario Land Surveyors' Association, Mr. W. E. McMullen, describes a re-survey of the Canadian Pacific Ry. line in New Brunswick, and the following notes have been taken from his paper: The general scheme of the survey was to make a center line traverse and tie in right-of-way fences, lot lines, parish and county boundaries, locate the properties of the various owners along the line, run rail levels, obtain approximately the original ground line, and note the dimensions of culverts, etc. For the field work two box cars were fitted up. The one with bunks and a drawing-table, and the other with a dining-table, stove, and quarters for the cook. The party was composed of an engineer in charge, transitman and two picketmen, a draftsman, a leveler and rodman, and three chainmen, who went ahead and paint-marked one rail every hundred feet. These last could cover eight or nine miles a day without much trouble, and, after getting their work well ahead of the party, were recalled to locate right-of-way, fences, culverts, etc. The leveler would cover about 4½ miles per day, and when he got too far ahead of the transit was recalled and ran a spare transit for a while. The transitman was paid $75 per month and draftsman the same; leveler, $60, and the others, most of them engineering students, $1.35 per day. The cook got $40 per month. The average progress of the field work was a little over two miles a day, and the average cost of the field work, exclusive of car furnishings and inclusive of wages and board, was $14 per mile. The cost of fitting up the cars with stoves, bunks, blankets, mattresses, tables, dishes, etc., amounted to about $150.

Cost of Two Railway Resurveys.†—The resurvey of a railway is a task which may involve little or much work, depending on the comprehensiveness of the records required. When the task is merely that of retracing alignment and locating tracks and structures the work is simple. When, however, the task comprises in addition, the topographical mapping of the line, right of way, buildings and structures and the recording of all co-ordinate information, an organization of the highest character and efficiency is absolutely necessary. In the text which follows we give from actual records the methods adopted in resurveying 581 miles of the Chicago & West Michigan Ry. and 389 miles of the Detroit, Grand Rapids & Northern Ry. These methods are not only of interest in themselves, but they are lent particular value by the figures of cost which accompany them. In studying these figures, however, it must be kept in mind that they represent wages and prices of 1893 to 1898.

**Engineering-Contracting*, Oct. 14, 1908.

†*Engineering-Contracting*, Sept. 5, 1906.

Chicago & West Michigan Survey.

In 1893 the Chicago & West Michigan Ry. started a resurvey of its road. The object of the survey was to obtain data for the preparation of a set of maps to show in as complete and accurate a manner as possible all of the company's track, right of way, buildings and other property, and all such other information relating to these items as could be obtained. The purpose was also to obtain similar information relative to the track and property of other roads at junction points.

Field Force and Outfit.—The field party consisted of three men: the assistant engineer in charge of the work and two rodmen. They were supplied with the following outfit: one double velocipede car, a transit, two 100-ft. steel tapes, one 50-ft. steel tape, one 50-ft. cloth tape, one small hand instrument for taking fence angles, etc., an axe, a maul, a set of branding irons, a set of steel dies, a tinner's stove, a paint pot and brush, a spade, a pick and a stock of pickets. The men boarded at hotels or, when more convenient, at private houses and usually moved every 10 or 15 miles accordingly as it was convenient to get board. Very little use was made of trains to get to or from work; the party, however, generally moved by train when going to new headquarters.

Chaining the Line.—The first work was to chain the track. This was done very carefully, and one of the 100-ft. steel tapes was reserved for this work alone. Ten (3/16-in. diam.) 12-in. chaining pins were used, and at every tally an 8d. nail was driven into the ballast or into a tie for reference in case a pin was lost or misplaced in the next 1,000 ft. The chain was carried in the center of the track and the half-gage was laid off from the right-hand rail at each station. For this purpose a 6-ft. picket was arranged with a lug on one end and a center mark. No corrections were made for grades or temperatures.

A paint mark was put on the flange of the right-hand rail opposite every station and at every 500 ft. a stake was driven 5 ft. to the left of the center line. These stakes were of oak, 3 x 3 x 30 ins. with 8-in. points, and were purchased already sharpened. They were distributed by freight train in lots to suit the distances covered by the field party from the various headquarters. All the stakes used from any one headquarters were marked at one time; for this purpose there were provided a firepot or tinner's stove, as noted above, and a set of from 0 to 9 cast-iron branding irons fixed to a handle of round iron some 15 ins. long. Section men usually helped to deliver the stakes between station stops. The stakes were driven so as to project from 4 to 6 ins. above ground and with the branded face toward the track.

It may be noted here that this work furnished incidentally an opportunity to study the advantage of using stakes treated with some preservative from decay. The stakes placed in 1893-4 were untreated and those placed in 1895 were dipped in hot coal tar and pitch. Similar stakes used on the Detroit, Grand Rapids & Northern survey in 1896 to 1898 were treated, those used in 1896 with

"Woodiline" used cold and those used in 1897-8 by dipping in hot Carbolineum. It was found upon examining in 1899 the stakes placed in 1893 that fully one-third were rotten or missing, and all of them had to be removed. It was also found that none of the treated stakes set in 1895 showed any signs of decay.

The stakes, as before stated, were spaced 500 ft. apart. At every mile a piece of T-rail 5 ft. long was set 20 ft. to the left of the center line, with the base facing the track and marked with the mile number by means of a steel stencil. Station and mile numbers were both continuous and read from the actual end of the rail at the terminal where the survey was begun.

Retracing Alignment.—The alignment was retraced by means of a transit, but not by running a continuous line. On tangents the direction was checked often enough to find all swings, by setting the transit over the gage side of the rail and taking a back sight on the rail and then reversing and sighting on the rail ahead. If any change in direction showed it was noted as an angle. When a curve was reached a point was marked in the center of the rail at or back of the point of curve, and then deflection angles were read to such station on the curve. When the transit had to be moved up the vernier was set at zero for a back sight on the last point and then the angles ahead were read on as before. When the point of tangent was reached a point was worked in the center of track between rails at or just ahead of the point of tangent; the angle was read to this and then the transit was moved up and the angle from the last rail point or chord to the tangent ahead was read. The direction of tangents was kept as azimuth, south being assumed as zero and angles recorded around by the west or clockwise.

Azimuth was determined by Polaris, stations for observations being selected so that the meridian would intersect a tangent. The angle to the tangent was then measured. An observation was taken about every 15 miles and the course of the tangents calculated from the angles measured along the center line. The two usually lacked from 0° to 0°-10′ of checking, and the difference was distributed among the angles around the curves. The method of determining the true meridian from Polaris was the one in the manual issued to surveyors by the Government Land Office, and known as the hour angle method. Whenever the difference in the longitude of two observations exceeded about 5 miles the correction made necessary by the divergence of the meridians was introduced. This amount was distributed over the line by adding or subtracting from the azimuth of tangents at their ends. By reason of this a long tangent which was in reality straight would have a difference of azimuth at its two ends. The determining of the azimuth of the line at different points was intended only as a check on the transit work, but probably the course of each tangent was correct with 0°-1′ or 0°-2′.

Topography.—The topography was in nearly all cases taken by measurements referred directly to the center line. All structures belonging to the permanent way, such as bridges, were recorded by plusses to each end or by a plus to the center and size. The length, size and kind of pipe or other culverts and of trestles, bridges,

open culverts and cattle guards were recorded. Right of way fences were carefully located by stations and plusses on line and by distance out at all points where any change in direction or distance out occurred. Track signs were located in the same way and usually the terms used to note them, as "Wh. Post," "Mile Board" and "Hy. Cross. Sign," indicated the use and construction in each case. Property line fences were shown by noting by stations and plusses the points at which they would intersect the center line and by measuring the angle of intersection. Highways and farm roads, highway crossings, farm crossings, gates, side drains at crossings, and ditches were all shown. The kind and make of rail and the date of rolling, with a description of joints and fastenings; the kind and condition of the ties; the kind and quality of the ballast; the kind of fence and the location and number of wires in the telegraph line were all shown and noted at the points where any change occurred. The kind of switch stand and kind and size of frog were noted. For buildings belonging to the company, the class, use, kind of foundation and point were noted. If possible, note was also made of the date of erection. Water stations, interlocking plants, etc., were usually described in detail.

Section lines, property lines and street lines were determined as accurately as possible. All monuments that could be found were located, the usual method being to produce the lines as indicated by the monuments to an intersection with the center line and record the angle with the distance measured along the monument line. For the purpose of tying the line to the village plots the field party was furnished with copies of all recorded plots, and with the aid of these sufficient tie lines were run to form a network on which the streets and lots could be plotted on the maps. Any additional information as to the company's right of way that could be found was secured. In these tie lines and also for all cross lines that intersect the center line on curves, the angle was read with the chord between the two adjacent transit points, but the plusses and distances out are from the actual center line intersection. No attempt was made to show the natural topography except in case of streams and of some very prominent ravines that intersected the line.

Mapping.—The maps were drawn on sheets of mounted egg-shell paper; the map sheets were 18 x 42 ins. and were bound in books containing about 25 to 30 miles of line. Three scales were used in mapping, 2,000 ft., 200 ft., and 50 ft. to the inch. The 2,000-ft. scale was used for an index map bound in the front of the book as a title page. On this sheet the railway was designated by a blue line on which tenth stations were numbered and mile posts shown by red lined blocks, with numbers referring to the particular large scale map (200 ft. or 50 ft.) on which the post came. The maps on the 200-ft. scale showed everything in the open country, but in cities where the same territory was covered by maps on the 50-ft. scale, much of the detail was left off in order that (1) what the company owned, (2) all recorded plots and (3) the lines to monuments in those plots might stand out clearly. As a rule, all buildings, etc., were put on and all figures

left off, the latter being confusing while outlines are not. Every fifth station was indicated by a red dot. The center line of the railway was shown by a ruled red line. Any territory shown also on the 50-ft. scale map was enclosed by a broken line in blue, with a designating number inside corresponding to the number of the special map. These special or detail sheets were inserted immediately after the general sheet referring to them. On the 50-ft. scale maps it was attempted to show everything that appeared in the note books; center lines were drawn in solid red and base lines in solid black.

The stations on all maps were numbered from right to left. In the upper right-hand corner of each sheet was lettered the first and last station number included in that sheet and also the number of the note book and its page numbers where the notes corresponding to the map data were to be found. The number, length, total angle and degree was written near each curve. Reverse curves counted as two curves. Station numbers were written across the center line and the numerals designating angles were written on an arc connecting the two legs. Azimuths were noted at each point of curve and point of tangent.

An abstract of such deed and indexed paper for right of way represented on any sheet was written on that sheet. In this abstract the following order was followed where possible: (1) Kind of deed and number by which it is known: (2) grantor; (3) grantee; (4) date of transfer; (5) description; (6) consideration; (7) agreement, and (8) date, book and page records.

The coloring used on the maps was as follows: For fences, yellow lines; for water, blue lines; for frame structures, gamboge; for brick structures, light red; for stone structures, a neutral tint; for platforms, sidewalks, farm crossings and for iron and steel bridges, Payne's gray; for railway property, Lake red; for streets, Vandyke brown. The tinting on the 200-ft. scale maps was ruled, but on the 50-ft. scale maps only a narrow wash around the edges was used.

Time and Cost of Survey.—The resurvey described was begun in April, 1903, and was completed in October, 1905, the work in the field occupying only eight months of the year. Paying the assistant engineer in charge $116.67 per month, rodman $65 per month, and chainman $60 per month, the following records of time and cost of surveying 152 miles were obtained:

	Days.	Cost.
Chaining and setting stakes..........	28¼	$279
Topography, taking notes............	57¼	561
Running section lines and corners...	24	237
Survey of station grounds...........	28¾	233
Running lines to village plots........	20¾	204
Total	205	$1,564

The totals give the labor cost per mile surveyed as $10.22, exclusive of leveling. The labor cost of leveling 127.8 miles was $166, making the cost per mile $1.30, and the time required for the work

was 20 days. The total cost of labor and materials for surveying 581 miles was as follows:

	Total.	Per mile.
Fieldwork, on survey	$ 5,238	$ 9.01
Fieldwork, material	392	0.67
Fieldwork, setting monuments	899	1.55
Material, setting monuments	415	0.71
Office work, plotting maps	5,546	9.54
Office work, materials	446	0.77
Copying village plots at county offices	752	1.30
Office work, copying notes, tables, etc.	1,050	1.81
Totals	$14,738	$25.36

A total of 609 monuments were set at a unit cost of $1.25 for labor and 44 cts. for material.

DETROIT, GRAND RAPIDS & NORTHERN SURVEY.

The resurvey of the Detroit, Grand Rapids & Northern Ry. for 389 miles began in July, 1896, and was completed in December, 1898. The method of work was the same as that described for the Chicago & West Michigan Ry., and the wages paid were the same except that the engineer in charge received $100 per month. The total cost of the survey and mapping was as follows:

	Total.	Per mile.
Fieldwork, on survey	$3,363	$ 8.64
Fieldwork, material	437	1.25
Fieldwork, setting monuments	765	1.97
Materials, setting monuments	265	0.68
Office work, plotting maps	3,323	8.55
Office work, materials	279	0.78
Copying village plots	215	0.55
Office work, copying notes, tables, etc.	234	0.73
Fieldwork, running levels, 351 miles	437	1.25
Fieldwork, plotting profiles	125	0.36
Totals	$9,364	$24.06

Cost of Railway Surveys.—In making a railway survey along the Columbia River, in open rolling country, my records show that a topographical party, consisting of 1 topographer and 2 rodmen, averaged 1½ miles a day, taking a strip 400 ft. wide, contours 5 ft. apart. A hand-level and tape were used. In this same country a leveler and rodman could readily run 6 miles of profile levels in a day, although it was safer to count on 4 miles.

On another similar survey in southern New York state, in comparatively level country, a transitman, 3 chainmen and a stake artist, averaged 2 miles of transit line per 8 hrs. Station stakes were set every 100 ft. This same party, later, took a belt of topography 500 ft. wide, at the rate of 1¼ miles a day, setting a transit up at each station and taking telemeter readings for distance and level readings for elevation with long bubble of transit.

The cost of a preliminary railroad survey, near Lake Erie, was as follows, using stadia measurements:

Chief of party	$ 5.00
Transitman	3.00
Recorder	3.00
5 rodmen, at $2	10.00
Total salaries per day	$21.00

This party ran 46 miles in 30 days, several of which were stormy, and they took a belt of topography 800 ft. wide. The cost was about $14 a mile, or $90 a square mile for the field work.

Using the chain method it took a party 24 days to run 45 miles.

In Trans. Am. Soc. C. E., Vol. 31, p. 81, Mr. M. L. Lynch states that one mile of line a day is a fair average in partly timbered country, for preliminary work. He gives the average cost of surveys at $60 a mile of located line.

Mr. Kenneth Allen states that in Kansas prairies he ran 312 miles of stadia line in 5.7 months, or 2.1 miles per day, a party costing as follows per day:

Transitman	$ 6.00
Leveler	4.00
2 rodmen, at $2.50	5.00
Axman	2.00
Teamster and team	3.00
Total per day	$20.00

The cost was $11 a mile. Bench levels were run ahead of the transit. The best day's run was 8 miles.

The Cost of Transit Lines in Heavy Timber.—In running transit lines through the dense timber of western Washington, for roads and railways, I have found that a party of 6 men (consisting of a transitman, two chainmen, two axmen and a flagman, who also served as an axman), averaged about 1,800 ft. of line run per 10 hours. It was exceptional that 2,000 ft. were averaged even for two or three days. No trees more than a foot in diameter were chopped; but the growth of great firs and cedars (occasionally one was 10 ft. in diameter), and the mass of fallen timber under foot made the advance slow. Where the timber was not so dense, it was possible to run from 3,000 to 5,000 ft. a day, setting station stakes every 100 ft. In running a traverse along a country road, where there was no tree-chopping at all, the same party would run 6 miles a day.

In running profile levels over these transit lines, a leveler and rodman would average 4,000 ft. a day in rough and densely wooded country; and 6,000 ft. in wooded country where the fallen timber did not retard walking so much. In all cases the actual time either on transit or level work averaged 8 hrs. per day, and about 2 hrs. per day were consumed in going to and from camp.

The foregoing records apply to lines aggregating several hundred miles in length, and are given partly from memory as my original detailed notes were lost in a fire.

Cost of Topographic Survey for 160-Acre Park.—In the State of Washington the author was in charge of a survey for a small city park of 160 acres. The work was done in August, 1892, with a party of 5 men, whose daily wages were as follows:

Transitman	$ 5.00
Recorder	3.00
2 chainmen, at $2.50	5.00
1 axman	2.00
Total per day	$15.00

This party was engaged 26 days in field work. In addition, a draftsman and computer was engaged for 40 days reducing the notes and plotting the map to a scale of 100 ft. to the inch, contours 10 ft. apart. The cost of the survey and map was, therefore, as follows:

Field work, 26 days, at $15	$390
Office work, 40 days, at $3	120
Total, 160 acres, at $3.20	$510

This is at the rate of $2,040 per sq. mile. This high cost was due to the roughness of the ground and to the fact that about half the area was densely timbered. The area surveyed was a hill about 350 ft. high, cut up by a number of gulches. A traverse line, 2 miles long, was first run to enclose the hill, station stakes being set every 100 ft., using a tape and transit. Then 10 parallel cross-lines were run along ridges through the woods over the hill, using tape and transit. The aggregate length of these cross-lines was 3 miles. Profile levels were taken with a Y-level along all the transit lines. Contours were located by means of the stadia, the transit being set upon hubs on the transit lines. The density of the timber greatly retarded the stadia work, due to the axe work necessary. Were I to repeat this work, I should run a traverse around the area as before, chaining and leveling; then all the necessary cross-lines over the hill would be run, using the stadia. Where woods are heavy it is necessary to run such cross-lines close together. I should increase the number of axmen, and have rodmen also serve as axmen.

Cost of Topographic Survey of St. Louis.—Mr. Oliver W. Connet gives the following: The area covered by triangulation was 30 sq. miles, the average length of the sides of the triangles being 1⅓ miles. About 92½ miles of precise levels were run in duplicate at a cost of $30 per mile, four benches per mile. The stadia method was used for topography, contours being 3 ft. apart, about 300 points being located by a party in a day. The party consisted of 1 topographer, 1 recorder, 3 stadia men, and 1 utility man. The average was 3.65 points per acre. The time of a party occupied in field work for 23⅓ sq. miles was: Triangulation, 62 days; precise levels, 114 days; topography, 248 days; total, 424 days. The cost was:

Triangulation	$ 1,812 or	11%
Precise levels	2,762 or	16%
Topography	6,060 or	36%
Office work (reduction of notes and plotting)	6,266 or	37%
Total	$16,900 or	100%

This is equivalent to $725 per sq. mile, or $1.13 per acre.

The average cost of the party per day, including transportation, instruments, etc., was:

Triangulation	$29.25
Precise levels	24.25
Topography	24.50

Cost of a Stadia Survey, Baltimore.—Mr. R. A. MacGregor, in Trans. Am. Soc. C. E., Vol. 44, p. 112, gives the following on the cost of a stadia survey of the City of Baltimore, Md. The map was plotted on a scale of 200 ft. to the inch, and fences, roads, houses (with some details of houses), 5-ft. contours, wooded and cultivated areas, creeks, etc., were shown. Everything was plotted in the field. The average error of closure was 1 in 700. The average number of shots was 6,400 per sq. mile. The number of shots per day averaged 180, the maximum was 349, all the plotting and sketching being done in the field. The shots were taken and recorded by the recorder, and plotted by the draftsman, who stood nearby; the topographer in charge did the sketching. The cost of this field work alone was $850 per sq. mile for an area of 33.3 sq. miles.

Cost of Topographic Survey, Westchester Co., N. Y.—Mr. G. L. Christian, in Trans. Am. Soc. C. E., Vol. 44, p. 115, gives the cost of making a survey in July, 1896, of a 57-acre tract of land in Westchester County, N. Y. Three-fourths of the tract was wooded, with much thick underbrush. The land was much broken, having a total rise of 150 ft., with slopes of 2% to 40%. The transit lines (12,750 ft.) covered the controlling points, stakes being set every 50 ft., and profile levels taken with Y-level. From these lines, with a hand level and tape, the 5-ft. contours were located. The map was plotted on a scale of 100 ft. to the inch. The cost per acre was as follows:

Running transit lines	$0.40
Running Y-levels	0.19
Contours with hand level	0.53
Stakes	0.07
Plotting transit lines	0.13
Plotting contour lines	0.15
Total per acre	$1.47

This is at the rate of $9.40 per sq. mile.

Cost of Topographic Survey Near Baltimore.—Mr. Kenneth Allen, in Trans. Am. Soc. C. E., Vol. 44, p. 113, gives the following relative to the cost of stadia surveys made for the Baltimore Sewerage Commission:

Survey.	I.	II.	III.	IV.	V.
Contour interval	5 ft.	5-ft.	5 ft.	2.5 ft.	2.5 ft.
Scale of map	1″=800′	1″=800′	1″=400′	1″=200′	1″=200′
Area, square miles	2.04	2.75	4.83	0.823	0.733
Area, timbered	......	......	47%	......	27%
Area, water surface	......	......	3%	12%	18%
Area, per day, water surface	0.157	0.131	0.079	0.052	0.052
Sal. per sq. mile	$54.90	$78.00	$140.20	$323.61	$256.21
Exp. per sq. mile	11.91	16.49	28.54	30.73	13.50
Cost per sq. mile	$66.81	$94.49	$168.74	$354.34	$269.71

These costs do not include mapping done in the office, but do include maps made in the field. In surveys I and V the ground had gentle slopes; in III the range of elevation was 125 ft., but in the other areas it did not exceed 40 ft. Comparing I and IV shows the increased cost where 2.5-ft. contours are located. Comparing I

and II shows the economy of reading bearings with a compass (instead of with a vernier) and setting up on alternate points which was done in survey I.

Mr. Kenneth Allen, in Trans. Am. Soc. C. E., Vol. 30, p. 614, gives the following data: A stadia survey made for the Philadelphia Water Department, in 1884, covered 446 square miles and occupied 162 days field work in the Perkiomen Water Basin, in Bucks, Montgomery and Lehigh Counties. The contours were 10 ft. apart plotted on a scale of 400 ft. to the inch. All roads, buildings and timber outlines were shown. The party consisted of 1 transitman and 1 rodman; the average area covered per day taking notes in the field was 0.434 square mile; the average area covered per day plotting in the field was 0.31 square mile.

On a survey in the Connellsville coke region, a survey similar to the above, but more detailed and plotted to a scale of 600 ft. to the inch, contours 10 ft. apart, covering an area of 168 square miles, cost $116 per square mile, including the location of farm boundaries, coal outcrops and areas, and the reduction of all previous surveys to the same scale. The cost of the field work on the topography alone was, however, only $40 per square mile, or about one-third the total cost. The cost of engraving and publishing was about $30 per square mile more.

Cost of Three Stadia Topographic Surveys.—Mr. F. B. Maltby, in Jour. Assoc. Eng. Soc., 1896, has an article on "Methods and Results of Stadia Surveying," from which the following abstracts have been made:

A party should consist of an observer, a recorder, and 2 to 4 rodmen. A good observer in open country can locate 500 points a day for a map of 500 ft. to the inch. This means about 5½ or 6 hrs. of actual observing, and gives an average of 1½ shots per minute. Two men using the Colby protractor (one calling off and one plotting) plotted 216 shots per hour, as the average of 25½ hrs.

A stadia line, 15 miles long, over which levels were run, checking on each stake, showed discrepancies between consecutive stakes as high as 0.2 ft., but the total error for the 15 miles was less than 1 ft.

The cost of stadia surveys varies widely. The topographical survey of Baltimore, for topography alone, excluding triangulation and precise levels, cost $1.50 per acre. The scale of the map is 200 ft. per in., and all buildings, streets, alleys, etc., are located. The cost of the topography of the survey of St. Louis was 73 cts. per acre, scale of map the same, but few buildings and few street corners were located. A topographical survey of 3,000 acres, near Madison, Ill., in 1893, cost 50 cts. per acre including mapping; scale was 400 ft. per in., and all buildings, fences, railroads, etc., were located.

Several different tracts of land near St. Louis, of 100 to 200 acres, were surveyed for 20 to 40 cts. per acre. In these cases a scale of 400 ft. per in. and a 2-ft. contour interval, and only the configuration of the ground were required.

A survey of 9,300 acres in southwest Texas, in 1894, was made; 2-ft. contours; and 400 ft. per in. scale; ground was rolling and partly covered with brush; condition favorable; cost, 7 cts. per acre.

Topographical work on the Mississippi River, in 1891, cost $36 per sq. mile; on the Missouri River, in 1895, $31 per sq. mile, or 5 to 5½ cts. per acre. Scale was 1,000 ft. per in., contours 5 ft. apart, all buildings, roads, fences, limits of culture, etc., located. This cost includes a system of tertiary triangulation, but does not include mapping.

Cost of Surveys, Erie, Canal.—Mr. D. J. Howell gives cost of making surveys for the Mohawk Ship Canal, 90 miles along the Mohawk Valley from the Hudson River westward to Herkimer. The work was done by stadia parties, consisting of 1 chief, 1 observer, 1 recorder and 4 rodmen. The area mapped was 47,400 acres, of which 6,600 are river. The average cost was 86 cts. per acre, including soundings of the river, field and office work, but excluding test pits and borings. Contours were 2 ft. apart; map scale 1 in 2,500. A cross-country survey, 25 miles long, embracing 7,600 acres (no villages or cities), cost 27 cts. per acre for the field notes and the reduction of the notes ready for plotting. The cost of the plotting was estimated to be about 23 cts. per acre more, making the total cost about 50 cts. per acre. The men were well trained and the weather was favorable on this 25-mile stretch.

Mr. William B. Landreth, in Trans. Am. Soc. C. E., Vol. 44, p. 92, discusses the methods and cost of stadia topographic surveys made to determine the location of reservoirs and conduit lines for the Rome level of the Deep Waterway on the Oswego-Mohawk-Hudson Route. The surveys were made between Aug. 1, 1898, and June 1, 1899, scarcely any time being lost from bad weather. A party consisted of 1 engineer in charge, 1 transitman, 1 recorder, 3 or more stadia rodmen, 2 or more axmen, 1 draughtsman, and 1 computer. Each rodman was given a particular class of work, one following streams, another taking roads, another woods, and so on. When convenient all rodmen kept on the same side of the transit. Contour intervals were 10 ft. on the Salmon River and the Black River surveys, and 5 ft. on the Fish Creek line. At the close of each day the field party reduced the stadia notes. The scale of the Salmon River and the Black River maps was 1 : 10,000, and of the Fish Creek map, 1 : 5,000. About 65% of the Salmon River area is covered with small second growth timber and swamps. The country is rough. The Black River Valley, between the villages of Carthage and Lyons Falls was surveyed up to the 790-ft. contour. Only 25% of the area is wooded, and the country is not very rough. The Fish Creek Valley, from 2 miles above Williamstown, to 2 miles below Taberg, a distance of 21 miles, was surveyed, the survey covering the valley and a portion of the side slopes to an elevation of 75 ft. above the creek. The ground was mostly grazing and farm land, 40% of which was timbered. The cost of the three surveys, including finished maps, traveling expenses, etc., was as follows:

	Salmon River.	Black River.	Fish Creek.
Area, square mile	15	85	19
Set-ups	771	600	451
Shots	3,838	11,166	11,776
Square miles per day	0.32	1.81	0.45
Field work per square mile	$66.00	$16.50	$54.00
Map work per square mile	14.00	7.00	25.00
Total per square mile	$80.00	$23.50	$79.00

Note.—The cost of the base line surveys for the Salmon River and Fish Creek work, and for one-third of the Black River, is not included in the costs above given; the costs include no leveling, but only the stadia field work and mapping, excepting on the Black River where base line and leveling costs for two-thirds the territory are included.

Cost of U. S. Deep Waterways Survey, N. Y.—Mr. A. J. Himes, in Trans. Am. Soc. C. E., Vol. 44, p. 105, gives the following data on the U. S. Deep Waterways Surveys for a 30-ft. canal along the Oswego and Mohawk Rivers, a distance of 91 miles. A sufficient number of stadia readings was taken to develop 2-ft. contours. About 83% of the area was mapped on a scale of 1:5,000; the other 17%, on a scale of 1:2,500. There were 12 sq. miles of soundings made in Oswego Harbor and Oneida Lake, and plotted; and an area of about 78 sq. miles of Oneida Lake and Oswego Harbor was determined by triangulation. There were, besides, 121 sq. miles of land topography taken. All buildings, roads, railroads, property lines, streams, orchards, swamps, etc., were located. A stadia party consisted of 1 instrumentman, 1 recorder and 3 rodmen, with sometimes 1 laborer for cutting brush or rowing a boat. Each night the party reduced the stadia notes and calculated the co-ordinates. The error of closures was readily kept within 1 in 700; and errors in elevation seldom exceeded 1 ft., being usually less than 0.5 ft. Sights 2,000 ft. long were often taken. Charts were found to be much better than tables for stadia reductions. The work was begun Oct. 23, 1897, and finished Nov. 5, 1898. In no month were more than 5 days lost on account of bad weather. The average number of readings was 1,440 per sq. mile. The minimum average area covered per day by one party on a single piece of work was 0.058 sq. mile. The maximum was 0.257 sq. mile. The average for the whole survey was 0.123 sq. mile per party per day. The cost was as follows per sq. mile:

Fieldwork	$179
Mapping	101
Total per sq. mile	$280

This is exclusive of swamps and lakes not sounded.

Cost of Government Topographic Surveys.—Mr. Marcus Baker, in Trans. Am. Soc. C. E., Vol. 30, p. 619, gives the cost of Government topographic surveys in many European countries, to which the reader is referred. The U. S. Geological Survey of New Jersey was begun in 1877 and finished in 1887, covering an area of 7,894 square miles, with contours 10 and 20 ft. apart. The cost was $6.93 per square mile, which includes all expenses in producing a map ready

for the engraver. The engraved map is on a scale of about 1 mile per inch. A similar survey of Massachusetts, made 1884-1888, contour interval 20 ft., cost $13 per sq. mile. A similar survey of Rhode Island, made 1888-1889, cost $9 per sq. mile. A similar survey of Connecticut, 5,004 sq. miles, made 1889-1890, on a scale of 1 mile per inch, 20-ft. contours, cost $9.80 per sq. mile for map ready for engraver.

A topographic map of the banks of the Mississippi River, from Cairo to the Gulf of Mexico, was completed by the Government in 1884, at a cost of $51 per sq. mile for 1,954 sq. miles of land and water surface. The manuscript map was on a scale of 1:10,000, embracing the river and a strip of land ¾ mile wide on each side. The river was carefully sounded.

Mr. Baker gives estimates of the cost of surveys made by the Coast Survey, but these estimates are strongly disputed, moreover they are of minor value to engineers in general practice, so the reader is referred to the Transactions for the data.

The N. Y. State Engineer's Report, 1897, gives the cost of topographical surveys, for the Dept. of the U. S. Geol. Survey, as follows per square mile, contours 20 ft. apart, and map on a scale of about 1 mile to the inch:

	Sq. mile.
Triangulating (1,370 sq. miles)	$2.00
Topography	8.70
Office work	0.60
	$11.30

The total cost of 15,118 sq. miles, for field and office work, had been $11.06 per sq. mile. A table giving the cost of 2,200 sq. miles shows a range of $4.35 to $25 per sq. mile, the average being $10.05 for field and office work, of which $8.43 was the cost of field work. The cost of office work ranged from $1.15 to $4.05 per sq. mile, and averaged $1.62.

Cost of Triangulation and Plane Table Surveys.*—During the spring of 1908 a triangulation system consisting of 48 signals and controlling about 150 square miles was installed on the Grand Valley Project (U. S. Reclamation Service), and during the field season of the same year a plane table survey of approximately 127 square miles was made and maps prepared on a scale of 1 in. to 1,000 ft. with 10-ft. contour intervals. A careful record of expenditures was kept and the itemized costs are shown below.

In the triangulation survey the signals consisted of 2 by 4-in. posts 14 ft. high, erected over pieces of ¾-in. gas pipe driven from 18 to 24 ins. in the ground and held erect by three guy wires to each post. The signals were arranged 2½ miles apart and where stations were required more frequently or section ties were required outside of the area mapped the charge for such work was made against the topographic mapping. The costs of triangulation survey shown include the cost of measuring base lines and of making Polaris observations. No camp was established, and subsistence was obtained at hotels and farm houses in the vicinity.

*_Engineering-Contracting,_ May 26, 1909.

COST OF TRIANGULATION SURVEY, GRAND VALLEY PROJECT.

Distribution.	Av. time per sq. mile, days.	Rate per day.	Cost per sq. mile.
Transitman	0.11	$7.50	$0.80
Transitman	.14	3.33	.46
Office engineer	.05	3.00	.14
Recorder	.05	3.00	.15
Flagman	.25	2.25	.56
Computer	.05	2.25	.12
Draftsman	.01	2.25	.02
Hired horses	.08	.50	.04
Government horses (depreciation)	.40	.25	.10
Depreciation of equipment	...	....	.03
Travel	...	....	.05
Subsistence	...	....	.29
Supplies, miscellaneous	...	....	.18
Supplies, stakes and monuments	...	....	.45
Supplies, repairs	...	....	.02
Supplies forage	...	....	.22
Total cost per square mile			$3.63

In the plane table survey the field party usually consisted of 1 plane table man, 1 recorder and 2 rodmen, but at times a driver was necessary for teams used by level and topographic parties. The camp teamster hauled the supplies necessary, but the men furnished their own subsistence by organizing a club. The cost of hay was $15 per ton and of oats $1.90 per hundred weight. The area mapped was fairly rough on the average, but the cost was quite variable. On level mesas the cost was as low as $18 per sq. mile, but where the area mapped consisted of small fruit farms with numerous buildings, roads, fences and irrigation and waste ditches, the cost ran as high as $75 to $80 per sq. mile.

COST OF PLANE TABLE TOPOGRAPHIC SURVEY, GRAND VALLEY PROJECT.

Distribution.	Av. time per sq. mile, days.	Rate per day.	Cost per sq. mile.
Project office expenses	....	.....	$1.63
Transitman	0.02	$3.33	.07
Flagman	.02	2.00	.04
Levelman	.47	3.00	1.41
Level rodman	.51	2.25	1.15
Driver	.31	2.00	.63
Topographer	2.90	3.00	8.69
Recorder	3.06	2.25	6.90
Stadia rodman	6.15	2.00	12.32
Hired horses	5.83	.50	2.92
Government horses (depreciation)	4.84	.25	1.21
Computer	.45	2.25	1.02
Draftsman (chief of party)	.58	3.33	1.93
Camp cook and teamster	3.70	2.00	7.41
Depreciation of equipment	....	....	2.68
Veterinary service	....	....	.04
Supplies, miscellaneous	....	....	1.28
Supplies, stakes and monuments	....	....	.63
Supplies, repairs	....	....	.51
Supplies, forage	....	....	4.50
Supplies, shoeing	....	....	.39
Traveling expenses for field party	....	....	.03
Subsistence for field parties remote from camp	....	....	.41
Total cost per square mile			$57.79

Cost of Topographical Survey, Texas.*—The survey covered about 900 acres of rolling hills near San Antonio, Tex., the range of elevations being something over 100 ft. The ground was heavily wooded with mesquite brush. Three roads in each direction which had been previously staked and cleared, provided a skeleton for horizontal control. Levels were run from a distance of two miles and bench marks established at intervals of one-third of a mile along the roads, the profiles of the latter being taken simultaneously. The details were then filled in by random stadia lines, run by compass and with short courses in such a manner as to avoid clearing. No permanent marks were used at set up points and only the alternate points were occupied by the instrument. The whole survey was made by a party consisting of instrumentman and rodman. Five-foot contours were obtained and the tract was mapped on a scale of 200 ft. to the inch.

The itemized cost of the survey and mapping was as follows:

Field work:	Total.	Per acre.
Party of two, 7 days, at $7.20	$50.40	
Labor extra	2.00	
Total	$52.40	$0.058
Office work:		
Platting and mapping, 1 man 10 days	$35.00	
Office expenses and materials	5.60	
Total	$40.60	$0.045
Grand total	$93.00	$0.103

For the above information we are indebted to Mr. Terrell Bartlett, C. E.

Cost of Two Small Surveying Jobs.†—The first job consisted of a transit traverse up Town and Hanging Kettle Creeks in Clay County, Miss., the work being done in November, 1907. A summary of the work is as follows:

Number courses Town Creek	34
Total distance	1.97 miles (10,415.4 ft)
Number courses Hanging Kettle Creek	19
Total distance	126 miles (6,629.3 ft.)
Number of courses in both creeks	53
Distance, both creeks	3.23 miles (17,044 ft.)
Average course	321.7 ft.

In the field work 3½ days were spent; while the office work, computing and mapping was 6 days. The working day was 9 hours. The cost of the field work was as follows:

Instrument man, at $5	$17.50
Two chainmen, at $1	7.00
Two rodmen, at $1	7.00
One axman, at $1	3.50
Total, 3½ days	$35.00

**Engineering-Contracting,* Nov. 11, 1908.
†*Engineering-Contracting,* April 22, 1908.

The office work cost $30; a draftsman and computer at $5 being employed for 6 days. The total cost was, therefore, $65.00, and the cost per mile was $20.12. The 1/16 section, ¼ section and section lines had been run across creeks, and ties were made to all such lines. All lines were run with transit and steel tape and all angles and lines checked before areas were computed. The map shows the acreage on each side of center line of creek in each 1/16 section (40 acres) crossed. The traverse was made on one bank, the creek being too deep to cross. The country was flat with scattering woods and bushes. The second job consisted of the survey of a convict farm in Mississippi, for a lumber company, the work being done during January, 1908; a summary of the work is as follows:

Cultivated land:

Number cuts	58	
Smallest acreage per cent	5	acres
Largest acreage per cent	16.54	acres
Total acreage	414.77	acres
Average acreage per cut	7.15	acres

The time in the field was 3½ days, and the time in office, computing and mapping, was 5 days; an 8-hour day was worked. The cost of the field work was as follows:

Surveyor, at $5	$17.50
Four helpers, at $1	14.00
Total, 3½ days	$31.50

The office work cost $25, a draftsman being employed for 5 days at $5 per day. The total cost was, therefore, $56.50, or 13.5 cts. per acre. For the above information we are indebted to Mr. Charles L. Wood, C. E.

Cost of a Level Survey for a Drainage Plan.*—In August, 1904, the U. S. Department of Agriculture had a level survey made in Clay and Yankton Counties, South Dakota, for the purpose of developing a plan for the drainage of the bottom lands of the Missouri River in those counties. A description of the manner in which this survey was made was given in the Annual Report of Irrigation and Drainage Investigations of U. S. Department of Agriculture and is reproduced herewith.

The first step was to collect such information concerning the land in question as could be obtained from the county records. Convenient plats for field use were made upon land office township blanks on a scale of 2 ins. to the mile. Upon these were traced all land office data and such roads, ditches, and sloughs as were shown on the county maps. A day was then spent in making a general reconnoissance by driving over the area, in order to become somewhat familiar with its general topography. In this reconnoissance it was seen that the section lines could be easily followed, as

**Engineering-Contracting*, Sept. 12, 1906.

where they were not marked by highways there were fences or turning rows located on them, and nearly all the one-quarter and one-sixteenth section lines could be approximately located on the ground by fence or field lines.

From the reconnoissance and the field plots it was found that field measurements could be obviated by using land lines for locations, and all additional data necessary could be obtained by running levels. The plan decided on and carried out consisted in running levels along parallel north and south section lines two miles apart, extending from the ridge which marks the high-water bank of the Missouri River to the foot of the bluff. A permanent bench mark of the Missouri River Commission survey furnished the datum for the levels. Levels were recorded at each one-quarter mile along the lines surveyed, the instrument being set midway between the one-quarter mile turning points. Turning points were taken on short wooden pegs driven to the natural surface of the ground. A target rod was used and read by both levelman and rodman.

A light two-horse rig, with driver, was kept on the line and used to convey the rodman from one turning point to another. As the rodman moved one-quarter mile at a time and there was usually a good road, there was a considerable saving of time in the use of the rig, which was also used for conveying the party to and from work and for carrying water, lunch, and such survey stakes as were needed.

From five to ten miles of level lines were run per day. The growth of high grass and weeds often retarded the work. The number of side shots which were necessary to secure desired data also cut down the days' run. Side lines were also run to the lowest points in sloughs or depressions one mile each side of the main line. Where there was water in the sloughs the elevation of the water surface was taken and the depth found by sounding from a boat or wading. The level of the surface of the water of both Missouri and James Rivers was also obtained. The high-water marks were also obtained from points located by residents, and the low-water marks were determined from the plots of the Missouri River Commission. Bench marks were established at nearly all section corners and were made by driving 30-penny spikes into corner fence posts or telephone poles at the surface of the ground, a blaze being made about 4 ft. above the spike and the elevation marked upon it. Each night the elevations were recorded in their proper locations upon the field plots.

After the completion of the level work, the line between the cultivated and wet land was sketched upon the field maps by personal inspection. After the data had all been collected and platted the interior watershed boundaries and lines of proposed ditches were located on the field maps. A corrected map on a scale of one mile to one inch was afterwards made up from the field maps. The cost of this survey (82 miles of levels) was as follows:

Survey:	Per mile.
Engineer, leveling, at $6 per day	$1.06
Engineer, special field examinations, at $6 per day	0.40
Rodman, at $1.75 per day	0.31
Livery hire, team and driver, at $3 per day	0.73
Railway fare	0.03
Total cost of survey	$2.53
Plans:	
Engineer, office work, at $6 per day	$0.88
Drafting supplies	0.016
Total cost of plans	$0.896
Total cost of survey and plans	$3.43

Regarding this preliminary survey, it should be said that only sufficient work was done to furnish the information required for developing a general plan, yet all levels are accurate and are connected with and checked upon Government river survey bench marks. A list and description of bench marks, which were fixed at each section corner of the surveyed lines, accompany the report and map which were filed with the auditor of Clay County, the expense of which is not included in the above memorandum. The survey was inexpensive, yet sufficiently full for forming a comprehensive plan for the drainage of 70,000 acres of land, and established a sufficient number of points from which future surveys for detail and construction work can be made whenever required.

Cost of Sounding Through Ice.—Mr. Joseph Ripley gives the following relative to the use of an ice boring machine, operated by bevel gear, for boring 3-in. holes through ice. Before the use of this machine, holes were chopped by axes at a cost of about 8 cts. per hole through 2 ft. of ice. With the machine, operated by two men, the average time was less than ½ min. per hole, through 26 ins. of ice, overlaid by 2 ft. of snow, including all delays. The time of actual boring was about 8 seconds per hole. The sounding party consisted of 1 chief, recording soundings, 2 men sounding, 6 men operating three boring machines, 2 men moving tag lines and marking places for holes, 3 men shoveling away snow after holes were bored, 1 gage observer and 1 cook. Such a party averaged 3,000 holes per day of 8 hrs. at a cost of $1,000 per month, the working day being 8 hrs. With 25 working days in a month, the cost is 1⅓ cts. per hole.

In U. S. Eng. Report, 1903, Vol. 10, Part 2, p. 1896, the following is given:

An ice boring machine will bore a 2½-in. hole through 2 ft. of solid ice in 5 secs. A party can take 300 soundings per hr. through ice 2 ft. thick, in water 23 ft. deep, holes spaced 10 ft. x 50 ft. The best record for 8 hrs. was 2,749 soundings, ice being 13 ins. thick. The cost of soundings was 3 cts. each for field work, including locating the holes.

SECTION XV.

MISCELLANEOUS COST DATA.

Prices of Materials, Supplies and Plant.—Prices are subject to such fluctuation that I prefer to prepare a complete schedule annually, which is published in *Engineering-Contracting*, the first issue in April of each year. Rates of wages of different classes of workmen in different parts of America are also given in that issue.

The Cost of Fences.—A barbed wire fence was built under the following specifications:

"Posts to be oak or tamarack, 5 ins. diameter and 8½ ft. long, spaced 16½ ft. apart, c. to c., and set 3½ ft. deep in the ground. The height of fence to be 4 ft. 9 ins., formed of four lines of 4-barb wire, spaced 12, 14, 15 and 16 ins. apart measured from the ground up."

	Per mile.
350 posts, including braces, at 10 cts.	$ 35.00
1,500 lbs. 4-point barbed wire, at 5 cts.	75.00
40 lbs. staples, at 5 cts.	2.00
Labor	43.00
Total	$155.00

This 10 cts. per post was a very low price, due to the fact that posts were cut from trees near the work. Posts are frequently 5 to 10 cts. per lin. ft. of post, where they are imported by rail.

Where rail fences are built, the posts are usually spaced 8 ft. apart c. to c., and set at least 3 ft. deep. The fencing specified by the Mass. Highway Commission consists of cedar or chestnut posts, not less than 6 ins. diam. and 6½ ft. long, set 3 ft. in the ground, and spaced 8 ft. c. to c., bark peeled off. A top rail, 4 x 4 ins., and a side rail, 2 x 6 ins., are specified to be of dressed spruce; and both rails are notched into the posts and spiked. The fence is painted with one coat of white lead and oil. The usual contract price for such a fence in Massachusetts is 15 cts. per lin. ft., or $890 per mile. There are 660 posts, and 12,300 ft. B. M. of spruce per mile.

The wire fences of the Louisville & Nashville Ry. have posts 7 ft. long, with seven wires spaced 4, 4, 6, 8, 10, 12 and 12 ins. from the ground up. For one mile of fencing the following materials and labor are required:

	Per mile.
3 barbed hog wires (7.7 lbs. per 100 ft.)	1,218 lbs.
2 barbed cattle wires (7.14 lbs. per 100 ft.)	754 lbs.
2 plain ribbon wires (6.66 lbs. per 100 ft.)	704 lbs.
Total wire per mile	2,676 lbs.
Staples	49 lbs.
Posts, 10 ft. apart	528
Bracing, 1 x 6-in. yellow pine, ft. B. M.	440
Labor	$105

In soft soil a good workman, using an 8-in. post hole digger, will dig 100 post holes, 2 ft. deep, per day of 10 hrs.

Cost of Barbed Wire Fences.*—The practice in spacing posts is variable, sometimes being 15 ft. centers, sometimes 24 ft. Farmers usually space fence posts a rod apart (16½ ft.). When the posts are spaced 20 ft. apart it is customary to support the wires between the posts by means of two wooden slats or wire stays, each 4 ft. long, and spaced about 7 ft. apart. These slats or stays prevent animals from spreading the fence wires apart in their efforts to get between them.

Bill of Material.—The standard fence used on the O. R. & N. has posts 7 ft. long, 20 ft. c. to c., and bedded 28 ins. in the ground. The first wire is 13 ins. above the ground and the rest are 13 ins. apart, except the space between the upper two, which is 14 ins. The bill of material is as follows per mile of fence:

265 posts, 7 x 7-in. x 7-ft., split cedar.
530 slats, 1 x 3-in. x 4-ft. fir.
21,120 lin. ft., or 1,410 lbs., two-point galvanized cattle wire.
16 lbs. staples, 1½-in., No. 9 polished.
26 lbs. staples, 1¼-in., No. 9.

The following is a bill of materials and their estimated cost (not including labor) for the standard "second class fence" on the N. P., per mile:

1,340	lbs. (21,120 lin. ft.) galv. barb wire, at 2¼ cts.	$30.15
280	lbs. No. 7 galv. wire stays (675 stays, 4 ft. long), at 2.8 cts.	7.84
16	lbs. 2-in. galv. wire staples (950 staples), at 2.35 cts.	0.38
2,800	galv. anchor fence clamps, at 80 cts. per M.	2.24
10	diagonal braces, 4 x 4 in. x 12 ft., 160 ft. B. M., at $15	2.40
225	cedar posts (6-in.), 7 ft. long, at 10 cts.	22.50
6	lbs. 60d nails, at 2.25 cts.	0.14
1	Eureka tubular gate, $4	4.00
	Total materials	$69.65

For the last ten years the contract price for the labor of building such fences as this has not varied much from $75 a mile in the far West.

We shall now give the actual cost of a number of jobs of fence work on a western railway, showing the range of costs:

Cost of a Seven-Mile Fence.—This fence was 7 miles long, built

*Engineering-Contracting, Aug. 21, 1907.

on ground that was rather rocky, making the cost of digging post holes quite high. The cost of the fence was as follows per mile:

Materials:	
1,300 lbs. barb wire, at 2.65 cts.	$ 34.45
400 lbs. fence stays (100), at 2.75 cts.	11.00
90 lbs. fence clamps (3,900), at 6 cts.	5.40
16 staples (1,390), at 2.70 cts.	.43
352 posts (15 ft. c. to c.), at 11 cts.	38.72
12 lbs. 40d nails, at 2.25 cts.	.27
Total	$ 90.27
Labor: Loading and Moving:	
3 hrs. foreman, at 25 cts.	$ .75
16 hrs. laborers, at 15 cts.	2.40
Total	$ 3.15
Removing Brush:	
1 hr. foreman, at 25 cts.	$ .25
30 hrs. laborers, at 15 cts.	4.50
Total	$ 4.75
Distributing Fence Material:	
3 hrs. foreman, at 25 cts.	$ .75
10 hrs. laborer, at 15 cts.	1.50
Total	$ 2.25
Building Fence:	
38 hrs. foreman, at 25 cts.	$ 9.50
240 hrs. laborer, at 15 cts.	36.00
Total	$ 45.50
Grand total labor	$ 55.65
Cost of labor and materials	$145.92

It will be noted that the cost of moving the gang of men once on this job was $3.15 per mile of fence, or $22 for this one move, in lost time of men. Such losses as this should not be forgotten, especially in estimating the cost of small jobs.

Cost of a 2,000-Ft. Fence.—This was a short fence with posts 16 ft. apart, 4 wires to the post. The exact length of the fence was 1,932 ft., or 120 panels of 16 ft., exclusive of 2 gates. There were 4 posts used for the gates and 8 posts used for braces. The cost of this 1,932-ft. fence was as follows:

Material:	
129 cedar posts, 7 ft., at 7 cts.	$ 9.03
7,755 ft. barbed wire, 426 lbs., at 2 cts.	8.52
500 fence staples, 6¾ lbs., at 1.75 cts.	.11
360 stays (4 ft.), 122 lbs., at 3.15 cts.	3.86
1,440 fence clamps, 36.6 lbs., at 5.25 cts.	1.89
Freight on posts	2.00
Total for 1,932 ft.	$25.41
Two Gates:	
4 cedar posts (7 ft.), at 7 cts.	$ .28
12 pcs. 1 x 6-in. x 18-ft. = 96 ft. B. M., at $15	1.44
4 lbs. 10d nails, at 2.82	.11
Total for 2 gates	$ 1.83
Labor:	
2.6 days foreman, at $2.50	$ 6.50
7.8 days laborers, at $1.50	11.70
Total labor	$18.20

Excluding the gates, the cost of the materials was $69.40 per mile, and the cost of the labor was $49.70 per mile, or a total of $119.10 per mile.

Cost of a 9,000-Ft. Fence.—This fence was of the same design as the one just described, the actual length being 8,974 ft.

The materials cost:

2,154 lbs. barb wire, at 2.76 ct.	$ 59.45
649 lbs. fence stays, at 2.75 cts.	17.85
149 lbs. fence clamps, at 5.95 cts.	8.87
26 lbs. fence staples, at 2.70 cts.	.70
577 posts, at 11 cts.	63.47
15 lbs. 40d nails, at 2.25 cts.	.34
1 lb. 10d nails, at 2.30 cts.	.02
2 lbs. 5d nails, at 2.25 cts.	.05
24 pcs. 1" x 6'-16' 192', at $8.50	1.63
Total cost of material	$152.38

This makes a cost of $89.63 per mile of fence, including farm gates, there being 4 such gates in the 9,000 ft. An additional cost was 32 posts used for anchoring and for braces, the 15 lbs. of 40d. were also used on the anchors and braces. All the fence material had to be hauled from one to two miles on push cars by the crew to distribute it, and some brush had to be cleared away to build the fence. This and the other labor costs were:

Distributing Material for Fence:	
Foreman, 7 days, at $65	$ 1.52
Laborers, 9 days, at $1.50	13.50
Clearing Brush to Build Fence:	
Laborer, 1 day, at $1.50	1.50
Building New Fence:	
Foreman, 3.3 days, at $65	7.15
Laborers, 37.3 days, at $1.50	15.95
Putting Up Farm Gate:	
Laborers, 2 days, at $1.50	3.00
Total labor	$82.62

A cost per mile of $48.60, making a total cost for materials and labor of $138.23.

Cost of a 2,640-Ft. Fence.—This fence was of the same design as those previously given posts 16 ft. apart, with 4 wires. The fence was exactly half a mile long, but the costs have been reduced to the cost per mile for convenience of comparison.

Materials:	Per mile.
21,360 ft. barb wire, 1,282 lbs., at 2.65 cts.	$ 33.98
978 fence stays, 394 lbs., at 2.75 cts.	10.84
3,912 fence clamps, 98 lbs., at 5.95 cts.	5.82
1,304 fence staples, 18 lbs., at 2.70 cts.	.48
330 fence posts, at 11 cts.	36.30
Total materials per mile	$ 87.42
Labor: Distributing Fence Material:	
4 days labor, at $1.50	$ 6.00
Erecting Fence:	
2 days foreman, at $2.50	5.00
20 days labor, at $1.50	30.00
Total labor per mile	$ 41.00
Total material and labor	$128.42

Labor Costs on Four Different Fences.—Having given the costs of materials and labor on several fences, we shall now omit the material item and give only the labor costs on fences, all of which had posts spaced 16 ft. apart, and 4 wires to the post. The first of these was 2,200 ft. long and the labor of erecting it cost at the following rate per mile:

	Per mile.
Hauling Out Fence Material:	
1.2 days foreman, at $2.50	$ 3.00
12 days laborer, at $1.50	18.00
Total	$21.00
Building Fence:	
1.4 days foreman, at $2.50	$ 3.50
16.8 days laborer, at $1.50	25.20
Total	$28.70
Grand total	$49.70

This did not include $9 of lost time moving the gang from another job to this one.

The next job was the building of a fence 2,600 ft. long. The ground was rocky, making it necessary to anchor most of the posts. The labor cost at the following rate per mile:

	Per mile.
Clearing Brush:	
2 days labor, at $2	$ 4.00
Building Fence:	
2 days foreman, at $3	6.00
34 days laborer, at $2	68.00
Total	$78.00

In addition it cost $18 for the lost time of moving the men from another job to this one. Two farm gates were erected, and the cost of each was:

1 farm gate	$0.90
2 posts for gate, at 10 cts.	0.20
Labor placing gate	2.00
Total	$3.10

The next job was a fence 2,300 ft. long. The labor cost at the following rate per mile:

	Per mile.
Distributing Fence Material:	
1.1 day foreman, at $3	$ 3.30
13.8 days laborer, at $1.50	20.70
Total	$24.00
Clearing Brush:	
2.4 days laborer, at $1.50	$ 3.60
Building Fence:	
1.1 day foreman, at $3	3.30
21.8 days laborer, at $1.50	32.70
Total	$36.00
Grand total labor	$63.60

In addition to this, the lost time moving to this job amounts to $10.

The next job was a fence 5,700 ft. long, and the labor cost at the following rate per mile:

	Per mile.
Distributing Fence Material:	
3.8 days laborer, at $1.50	$ 5.70
Building Fence:	
1.8 days foreman, at $3	5.40
16.6 days laborer at $1.50	24.90
Loading Barb Wire on Car:	
0.5 day foreman, at $2.50	1.25
2.5 days laborer, at $1.25	3.13
Grand total labor	$40.38

Fence 5,000 Ft. Long.—The posts in this example were 20 ft. center to center. One gate was built. The material cost:

254 fence posts, 4.5 cts.	$11.43
1,215 lbs. No. 9 galv. iron wire, 2 cts.	24.30
285 lbs. fence stays, 3.75	10.65
96 lbs. fence clamps, 6.25 cts.	6.00
13 lbs. fence staples, 2.20 cts.	.29
1 lb. 40d nails, 1.5 cts.	.02
3 pcs. 2" x 6"-16' 48', $11.50	.55
	$53.24

Labor cost as follows:

Foreman, 6 days, at $48.75	$ 9.67
Laborers, 18 days, at $1.50	27.00
	$36.67

Making a cost per mile for material of $55.96, for labor $38.52, and a total cost $94.48. This includes one gate.

Cost of a Wire Fence.*—Mr. F. W. Doolittle gives the following data on 6,650 ft. of 4-wire fence, posts spaced 16 ft., as built recently about the top works of a coal mine near Denver, Colo. The work was done by regular employes on idle days during the summer, which accounts for lack of uniformity in day wages, and also for a comparatively high labor cost. No special item of superintendence is charged as the force was so small that the overseer also made a hand. The cost of the 6,650 ft. was:

Labor:	
Surveying line, 3 days, at $2.50	$ 7.50
Digging holes, 14 days, at various	26.00
Setting posts, 7½ days, at $2.50	18.75
Stretching wire, 8½ days, at various	23.50
Total labor	$ 85.75

Materials:	Cost.	Freight.	Hauling.	Total.
Posts	$75.00	$25.00	$6.50	$106.50
Wire	56.42	2.59	1.25	60.26
Staples	3.52	(Included in wire)		3.25
Total materials				$170.01

*Engineering-Contracting, Nov. 25, 1908.

An 8-hr. day was worked. The item, digging holes, includes 1 day, man and team, at $3.50, and the item setting posts includes 1½ days at $2.50, setting braces. The holes were dug with post auger to a depth of about 12 ins., where the ground was too hard for further progress. The holes were then filled with water, after which they could be deepened to from 20 ins. to 24 ins., or as far as the earth had been dampened.

Wires were stretched as follows: The reel was mounted on back of wagon box and several hundred feet of wire reeled off. The back end of wagon was then raised off the ground and a post placed between the rear axle and the ground to prevent the wagon running back. The rear wheel was used as a tightener by taking a couple of turns of wire about hub and turning wheel around by hand, or by a bar through spokes against wagon bed.

A comparative cost per mile of the above fence and the fence at San Antonio, Tex., described by Mr. Tyrrell Bartlett, in our Nov. 11 issue is as follows:

	San Antonio. Per mile.	Denver. Per mile.
Materials:		
Posts	$ 56.30	$ 85.20
Wire and staples	48.20	50.80
Total materials	$104.50	$136.00
Labor:		
Digging holes	$ 40.40	$ 28.80
Setting posts, tamping posts, stringing wire	35.50	33.80
Running line	.....	6.00
Total labor	$ 75.90	$ 68.60
Grand total	$180.40	$204.60

The chief difference lies in cost of posts, those used near Denver costing 50% more than those used at San Antonio. At San Antonio 5-in. cedar posts, set 30 ins. deep and 15 ft. on centers, were used, with four strands of wire. The labor on the holes was paid by the hole according as each was in earth, part in, or all in adobe. Other labor, $1.50 per day.

Cost of Digging Post Holes for a Fence.*—In building the levees along the Mississippi River to retain the waters within its banks, fences are erected on both the land and river side. The price paid for this work is included in that for excavation.

The fences are built with posts 5 ins. square, 7½ ft. long, 2½ ft. being in the ground. These posts are of oak, mulberry, black locust or sassafras, cut in the local timber lands. They are spaced 12 ft. apart. Four galvanized barbed wires are stretched and attached to the posts.

Along the Mississippi at present foremen are paid $100 per month and board, while laborers are receiving $1.75 for a 12-hr. day. The materials and labor give a cost of a single line of fence per mile of $125, which is quite low.

**Engineering-Contracting*, Aug. 28, 1907.

The post holes are dug with post hole augers, the holes being 6 ins. in diameter and 2½ ft. deep. In the soil that occurs along the river, one man with a 6-in. auger, working 12 hrs., will dig on an average 100 holes. This means a cost of 1¾ cts. for labor for digging a hole, and, as there are 440 holes to a mile of fence, the cost of digging the holes per mile will aggregate $7.70.

From each hole is excavated ½ cu. ft. of earth, and, with a 6-in. auger digging to a depth of 2½ ft., the cost of excavating a cubic yard of earth is 94½ cts.

Assuming that for a 10-hr. day a man would do proportionally the same amount of work, with wages at $1.50 per diem, we then have 84 holes dug in a day, making a cost of 1.8 cts. per hole, and cost per mile of $7.92. With the national government enforcing the 8-hr. law on the levee construction that is to be done under United States engineers, the number of holes dug a day may be decreased.

Cost of Digging Post and Pole Holes.*—A post hole digger may be termed a tool that does its digging by being driven into the ground, and, as it loosens the earth, picks it up so it can be taken out of the hole.

An auger is not driven into the ground like a digger, but is forced down into the ground by a man pressing on it, while at the same time he turns it as a carpenter does an auger in boring a hole through wood.

When digging a hole with a shovel and bar, it is seldom less than 12-in. wide at the top, but it loses about one-third of its diameter as it is taken down, when the holes are not over 3 ft. deep. This is due to the fact that the shovel used for this purpose cannot be worked in a smaller hole. Time is lost in hard ground by having to change from the shovel to the bar, as it is necessary to use the latter to loosen the earth.

We are enabled to give a record of digging some post holes by hand with the bar and ordinary long handled shovel. The fence posts were 7½ ft. long, 2½ ft. being put into the ground. The diameter of the post was 6 ins. The soil was a red clay. The holes being 2½ ft. deep, were 12 ins. in diameter at the top, but averaged 10 ins. This made 1⅜ cu. ft. of excavation for each hole. The wages paid to the laborers were $1.50 for a 10-hr. day. A man dug 40 of these holes per day, thus excavating about 2 cu. yds. of earth each day. This made a cost of 3¾ cts. per post hole dug, and a cost of 75 cts. per cu. yd. of excavation. With 440 post holes to a mile of fences, posts being on 12-ft. centers, this cost per post gives a cost per mile of $16.50.

A comparison of this with the cost of similar work done with an auger will no doubt be of interest. In *Engineering-Contracting* for Aug. 28, 1907, page 133, are given some costs of digging post holes with an auger. On that job 5-in. posts were used, and the holes were dug with a 6-in. auger, the holes being 2½ ft. deep. Only ½ cu. ft. of earth was thus excavated from the hole, as compared to 1⅜ cu. ft. One man in a 10-hr. day with wages at $1.75, dig-

**Engineering-Contracting,* Dec. 18, 1907.

ging 84 holes, made a cost of 1.8 cts. per hole, or a cost per mile, 440 holes, of $7.92. Thus it is seen that with a higher wage the cost was more than 50% less, which needs no comment in estimating the value of the patent digger and auger.

Another example of the cost of digging holes by hand was in making holes for some 12-in. steel channels that were to be used as the posts for a large storage bin for coal. The 12-in. channels were 24 ft. long, and 4 ft. of them were to be buried in the ground, embedded in concrete. For this reason the holes were made 2 ft. in diameter and 4 ft. deep.

The tools used in digging the holes were a digging bar, a shovel and a spoon. The holes were kept 2 ft. diameter to the bottom, the spoon allowing this to be done. From each hole 12½ cu. ft. was excavated. One man dug 3 holes of this kind a day. The ground was a stiff clay, and all of it had to be loosened with the bar. With wages at $1.50 per 10-hr. day the cost per hole was 50 cts. In a day a man excavated 1.39 cu. yds. of earth, which made a cost per cu. yd. of $1.08. Some of the patented diggers are adapted to this work and would no doubt have reduced this cost.

Cost of Digging 600 Trolley Pole Holes.*—Holes for trolley poles are generally dug by hand. Under most specifications they are not paid for by the hole, but are included in the price of other line work. For this reason few records of the cost of digging these holes have been kept. Poles used in large cities are generally of iron, and embedded in concrete, while those used in the smaller towns and on suburban roads are of timber. A different size hole is needed for each kind, so the cost of the holes varies somewhat.

In this article we will give the cost of digging more than 600 holes for trolley poles on a suburban line. The overhead construction was of two kinds, span wire which needs a pole on each side of the track, and single poles with a bracket to hold the trolley wire. This divided the work into two groups, and the span wire construction was further divided into double and single track work. The class of material in which the holes were dug, as well as the size of the butt of the pole, made additional division of the work. The cost of the work will be given under five groups.

A 10-hr. day was worked and the foreman was paid $3.00 per day and the laborers $1.50. The work was done during the months of February to July. The gang of men worked at digging the holes, raising the poles, and other overhead work during this period of time, but the cost of each item of work was kept separate. In digging the holes, the tools that the men used were: A digging bar, see Fig. 1; a round point shovel, see Fig. 2, and a spoon, see Fig. 3. The length of the handles on these was 8 ft. The holes were spaced as follows: For span construction on tangents, the poles were 110 ft. apart. On 12° curves or less they are from 80 to 110 ft. apart, while on curves of 150 ft. radius or less they were spaced from 40 to 50 ft. apart.

**Engineering-Contracting*, March 4, 1908.

Group I.—In this lot 82 holes were dug. It was for span construction of 4,775 ft. of double track. The poles were from 12 to 15 ins. in diameter at the butt, so the holes were dug about 2 ft. in diameter. The depth of the hole was governed by the specifications, which called for all holes to be 6 ft. deep, this depth to be in the natural ground. Hence, where there was an embankment, the hole had to be as much deeper than 6 ft. as the height of the embankment was above the natural ground at the place where the pole was to be planted.

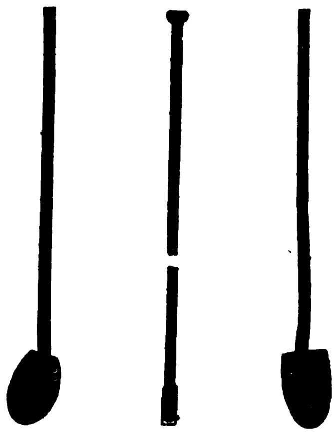


Fig. 1 Fig. 2 Fig. 3.

Eng.-Contr.

This is an instance of where conditions surrounding work may change, yet specifications are not changed to suit the new conditions. When these specifications were first drawn, all the poles on suburban lines of the company in question were not placed equi-distant from the center line of the track. In cuts they were so spaced, but, wherever embankments occurred, longer poles were used, as the poles were placed outside of the toe of the slope of the embankment. This prevented having the poles in line, which made the line of poles appear unsightly, and it also added to the length of the span wire. For these and other reasons, the arrangement of poles was changed and they were set equi-distant from the center line on the embankment as well as in the cut. Under these circumstances where the embankments had settled and were made of good material, there was no need of making the holes more than 6 ft., but, as the specifications called for a greater depth, the holes were so dug. They varied from 6 to 12 ft. deep. In this group 40 pole

holes were dug 6 ft. deep, the rest being from 9 to 12 ft., 30 holes being of the last named depth. The roadbed on this section was all embankment, made of cinders and slag from a steel plant. In digging the 30 deepest holes the cinders and slag kept running into the holes, causing about three to four times as much material to be excavated as would otherwise have been taken from the hole. It was estimated that this doubled the yardage excavated from the 82 holes.

In order to brace the poles under ground, an 8-ft. second-hand

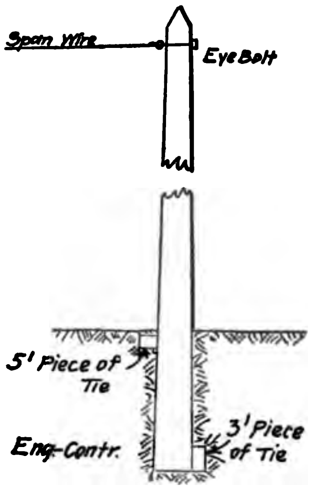


Fig. 4.

sawed tie was cut into two pieces, one 3 ft. long and the other 5 ft. long, and placed as shown in Fig. 4. The short piece was put in the bottom of the hole and the large pieces at the top. This also increased the amount of material that was taken from the holes. This extra material averaged 4 cu. ft. for each hole, and the contractor was paid extra for this work. When holes were dug of a greater depth than the length of the shovel handle, a foot or more of earth was dug out of the surface of the ground at the side of the hole, and the workman stood in this depression, thus allowing him readily to reach with his shovel and spoon to the bottom of the hole.

The cost of digging the 82 holes was:

Foreman	$ 27.90
Laborers	95.25
Total	$123.15

The unit cost was as follows:

	Per cu. yd.	Per hole.
Foreman	$0.13	$0.34
Laborers	0.47	1.16
Total	$0.60	$1.50

The high cost was due to the cinders as previously explained.

The cost per lineal foot of double track for the hole digging was 2.6 cts.

Group II.—All of these holes, 88 in number, were 6 ft. deep. The poles were a little heavier than those in Group I, so the holes were 2½ ft. in diameter. Each hole had 28 cu. ft. of earth in it, thus making 91 cu. yds. for all the holes. This was the first work done, and the men were not accustomed to handling their long handled shovels.

The cost of digging the holes was:

Foreman	$ 23.10
Laborers	83.10
Total	$106.10

This gave a unit cost of the following:

	Per cu. yd.	Per hole.
Foreman	$0.25	$0.27
Laborers	0.91	0.94
Total	$1.16	$1.21

As there was 4,590 lin. ft. of double track, the cost of digging holes per lineal foot was 2.3 cts.

Group III.—This was span wire construction for single track work, there being 17,160 lin. ft. of track. In all 320 pole holes were dug. The holes averaged 3½ ft. in diameter, and were from 6 ft. to 12 ft. deep. About 20% were deeper than 6 ft., 10% being 8 or 9 ft. deep, and 10% from 10 to 12 ft. deep. From the holes 510 cu. yds. of earth were excavated, being 1.6 cu. yds. as an average from each hole. This large size hole was needed because the poles were extremely large in diameter and heavy—much larger than they were needed. This, too, was owing to the specifications, which stated the smallest size in diameter that would be accepted, but failed to state the largest dimensions that would be taken. Some of the poles furnished by the timber contractor were 3 ft. or more in diameter at the butt. This not only added to the cost of digging the holes, but also to the setting of the poles, and other details of the work. Special eye bolts had to be made for a large number of the poles, and some longer crossarms had to be obtained to carry the feed wires.

Ten of the 6-ft. holes were dug in quicksand. These gave some trouble, and additional expense. An expedient used in digging these holes was to take a barrel, and, after knocking the two heads out of it, to put it in the hole. Then all the excavation was done from within the barrel, sinking it as the hole was dug. Thus the sides of the hole were sheathed, and by means of a hand pump the water

was kept out while the digging was going on. If the quicksand occurs for a greater depth than the height of one barrel, a second barrel should be used on top of the first. This second one should be a little larger than the first, so it will go down around the lower one. The pole must be raised in such a hole as soon as it is dug.

The total cost of digging the 320 holes was as follows:

Foreman	$ 77.80
Laborers	349.35
Total	$427.15

This gave the following unit cost:

	Per cu. yd.	Per hole.
Foreman	$0.13	$0.24
Laborers	0.68	1.09
Total	$0.81	$1.33

The cost per lineal foot of single track for the hole digging was 2.5 cts.

Group IV.—This was for 2,188 lin. ft. of single track, a branch of the other line. The curves were sharper, hence the poles on the curves were closer than on the main line. The poles were all less than 20 ins. in diameter, so the holes were made 2 ft. in diameter. There were 64 poles, and only a few of the holes were deeper than 6 ft. About 19 cu. ft. were excavated from each hole, no underground braces being used. This made 45 cu. yds. excavated from the 64 holes. The cost of digging the holes was:

Foreman	$ 9.00
Laborers	40.50
Total	$49.50

The unit cost was as follows:

	Per cu. yd.	Per hole.
Foreman	$0.20	$0.14
Laborers	0.90	0.65
Total	$1.10	$0.79

The cost per lineal foot of single track for the digging was 2.2 cts.

Group V.—This was side pole construction for single track, using a bracket made of pipe, on the pole. There were 5,700 lin. ft. of this construction, the poles being spaced about 80 ft. apart. Only a few of the holes were deeper than 6 ft., but, as the poles were large, the holes were 3½ ft. in diameter. The bracing blocks were used for these poles. An average of 36 cu. ft. was excavated from each hole, and, as there were 69 holes, 92 cu. yds. were excavated.

The cost of digging the holes was:

Foreman	$12.00
Laborers	54.00
Total	$66.00

This gives a unit cost of:

	Per cu. yd.	Per hole.
Foreman	$0.13	$0.18
Laborers	0.59	0.78
Total	$0.72	$0.96

The cost per lin. ft. of single track was 1.2 cts.

A comparison of the cost of each group is shown in the following table, also the average cost for the entire job:

	Cost per hole.	Cost per cu. yd.	Cost per lin. ft. Double track.	Cost per lin. ft. Single track.
Group I	$1.50	$0.60	$0.026	......
Group II	1.21	1.16	0.023	......
Group III	1.33	0.81	.....	$0.025
Group IV	0.79	1.10	.....	0.022
Group V	0.96	0.72	.....	0.012
Average	1.24	0.82	0.0245	0.0235*

*Bracket construction (Group V) left out of this average.

It will be noticed that the cost per hole varied directly with the size of the hole. Adding to the diameter and the depth increased the cost. The cost per cubic yard was high when the hole was small and low when the hole was large. The cost per lineal foot for span wire construction varied but little. Naturally the single track was about the same as double track.

Weight of Ashes, Garbage, Etc.*—In the Transactions of the American Society of Civil Engineers for April there is a valuable paper by Mr. H. de B. Parsons, entitled "Disposal of Municipal Refuse and Rubbish Incineration." From that paper we have abstracted data that may be of use to our readers.

Mr. Parsons gives the following as average weights per cubic yard:

	Lbs. per cu. yd.
Rubbish (paper, rags, old furniture, etc.)	200
Street sweepings	850
Garbage	1,150
Ashes	1,350

The weight of ashes varies from 1,200 lbs. to 1,500 lbs. per cu. yd. Ordinary household ashes contain about 15% of unburned coal; but steam-ash averages about 24% to 30% coal, the lower figure being for bituminous, and the higher figure for anthracite coal.

Mr. Parsons states that the mixed ash collections from New York City contains 30% to 35% combustible matter.

Rubbish, as ordinarily piled in carts, or without extra packing, weighs 130 lbs. to 225 lbs. per cu. yd. In Boston it averages 202 lbs. per cu. yd.; in New York it averages about 140 lbs.

The weight of street sweepings ranges from 800 lbs. to 1,400 lbs. per cu. yd., depending upon the dryness of the weather and the time of collection.

*_Engineering-Contracting,_ July 18, 1906.

A large table is given by Mr. Parsons showing the average per capita weights of city refuse collected in different cities. From that table the following was deduced, showing the average collection of refuse per capita per day:

	Lbs. per day.
Garbage	0.53
Street sweepings	0.50
Ashes	2.23
Rubbish	0.21
Total per capita	3.47

Cost of Garbage Reduction and Collection at Cleveland, O.*—The city of Cleveland, O., owns and operates its own garbage collection and reduction plant. This plant had cost the city on Dec. 31, 1906, a total sum of $181,307, divided as follows:

Reduction plant (incl. $15,000 bldgs.)	$146,297
Collection plant	35,010
Total	$181,307

In acquiring the plant the city has assumed a debt of $155,000 in bonds, the interest on which is paid by the city out of general funds. The reduction plant includes 50 acres ($25,000).

During the year 1900 there were collected and treated by the city plant 69,872,000 lbs., or 34,891 tons of garbage. The cost of this collection and treatment is given in detail in a report presented to the Cleveland City Council by the Board of Public Service, Mr. W. J. Springborn, President. Mr. Springborn has furnished us a copy of this report for examination, and from it we have taken the statistics given above.

The figures of most value and interest, however, are those showing by items the income and the operating expenses of the plant for the last calendar year. These figures are of value particularly because they give us specific costs of collecting and of treating garbage by the reduction process with a well managed and reasonably well designed and equipped plant. Prices of supplies and wages of labor are not given and various other important data are omitted.

We give in Table I the itemized operating expenses for collecting and reducing 34,891 tons of garbage at Cleveland, O., in 1906. The totals are as they are given in the report, but the several items have been extended by us to give the unit costs as well as the totals. It may be noted also that the totals are given separately in the report for the two half-year periods, Jan. 1 to June 30 and July 1 to Dec. 31; we have not made this separation. The figures given are the actual costs of collecting and reducing the garbage; these costs may be summarized as follows:

	Per ton.
Collection	$2.127
Reduction, per ton	2.385
Extraordinary expenses	0.253
Total	$4.765

**Engineering-Contracting*, May 2, 1907.

This total, it is to be noted, does not include interest on the bonds, which at 4% would be $6,200, or nearly 18 cts. per ton of garbage handled; nor does it include any charge for general administration expenses, a wholly indeterminate sum. Adding the interest charges brings the total cost per ton to $4.945.

The net cost to the city of collection and reduction is of course a less amount since the reduction process preserves the grease and other salable products, which are disposed of and constitute a source

TABLE I.—ITEMIZED COST OF OPERATING GARBAGE COLLECTION AND REDUCTION PLANT AT CLEVELAND, O.

	Total.	Per ton.
Labor at plant	$ 43,732	$1.254
Coal at plant	19,980	0.572
Superintendence and clerk	3,363	0.096
Repairs and renewals	4,763	0.136
Press cloths	2,565	0.073
Insurance	288	0.008
Office supplies	146	0.004
Oil, waste, light, water, etc.	5,113	0.146
Press racks	806	0.023
Taxes	346	0.009
Commission, analysis, etc.	826	0.023
Freight, purchase dead animals	1,455	0.041
Total reduction expenses	$ 83,383	$2.385
Labor, teamster, etc.	43,829	1.256
Feed	10,991	0.315
Freight on garbage	5,285	0.151
Superintendence and clerk	2,870	0.082
Shoeing, etc.	2,431	0.069
Harness repairs and renewals	1,204	0.034
Painting garbage cars	919	0.026
Repair cars and wagons	4,280	0.123
Rent and taxes	473	0.014
Insurance	450	0.012
Oil, light, telephone, etc.	1,601	0.045
Total collection expenses	$ 74,334	$2.127
Auditing	150	0.004
Loss of horses	1,473	0.042
Depreciation reduction plant, at 10%	3,382	0.097
Depreciation collection plant, at 10%	3,351	0.095
Depreciation new reduction equipment	536	0.015
Total extraordinary expenses	$ 8,892	$0.253
Grand total operating expenses	$166,609	$4.765

of income which is credited against operating expenses. There are also at Cleveland minor sources of income. The report mentioned above summarizes the income account as follows:

Product sold	$ 96,351
Inventory of product	8,694
Sale of raw material	354
Rents	127
Miscellaneous revenue	1,465
Total income	$106,991

We have then the following net cost to the city of treating one ton of garbage:

Total cost of disposal, per ton	$4.945
Total income from operation, per ton	3.07
Net cost of disposal, per ton	$1.875

It will be seen by referring to Table I that the total cost of reduction proper was $2.385 per ton, not including depreciation and interest on cost. Adding these two items we get a cost of about $2.62 per ton, so that the income for operation gives a profit on reduction alone of 45 cts. per ton. These figures are significant, not as specific guides as to the cost and profit of reduction, but as indicating that the reduction process of garbage disposal may be made self-supporting.

The income from operation comes chiefly from the sale of product. The nature and amount of this product are indicated by Table II, rearranged from figures given in the report. In addition to the character and quantities of materials produced for sale the table shows the prices fetched by these materials in the market. It is interesting to note that the amount of grease per ton of garbage treated was 61.05 lbs., or 3.06%.

In considering the figures given it is important to remember that they are a record of an individual case. They are interesting as being almost the first and certainly the most complete published figures of the cost of garbage disposal by reduction, and for this reason they have been given.

TABLE II.—SHOWING CHARACTER AND VALUE OF SALABLE PRODUCT FROM CLEVELAND, O., GARBAGE REDUCTION PLANT.

Article.	
Grease, 2,140,300 lbs.	$41,940
Dry tankage, 6,282,500 lbs.	13,724
Pressed tankage, 2,315,400 lbs.	2,564
Hair	87
Tails	45
Hides	1,493
Total	$59,853

Cost of Garbage Disposal, Milwaukee.—Mr. Rudoph Hering is authority for the following data. The weight of garbage is:

	Per cu. yd., lbs.
Ashes and rubbish mixed	1,040
Dry manure	970
Clear ashes	1,210
Rubbish alone	650

A horse produces 22 lbs. of manure daily.

In 1906 the city had a population of 350,000. The garbage collected was 48,400 loads, or 38,500 tons, of which 35,300 tons were burned in a furnace. It required 160 lbs. of coal to burn a ton of garbage, coal costing $3.80 per ton, which is equivalent to 19 cts.

per ton of garbage. There are 8 tons of residual ash from each 150 tons of garbage.

The cost per ton in 1906 was:

	Per ton.
Collection	$1.66
Operating hoist	0.10
Operating furnace	1.24
Burial	0.01
Total	$3.01

The cost of the crematory plant was approximately as follows:

Buildings	$16,795
Steel trestles	3,510
Hoists	2,900
Engines and dynamos	4,113
Pump	494
Chimney (150 ft. high)	6,399
Three furnaces	27,750
Patent rights	12,500
Total	$74,461

Garbage Incineration, San Francisco.—The garbage is cremated by a private company for 20 cts. per cu. yd., garbage being delivered by the city at the plant. The plant was built in 1897 at a cost of $75,000, and handles 650 cu. yds., or about 260 tons per day, which is less than half its capacity as no force works nights.

The following gang works 11 hrs. (in 1900):

1 foreman	$ 2.50
1 office man	2.50
1 night man	2.50
5 firemen, at $1.75	8.75
5 firemen-helpers, at $1.50	7.50
10 men on garbage floor, at $1.625	16.25
Total	$40.00

This labor is equivalent to 6 cts. per cu. yd., or 15 cts. per ton, but does not include the disposal of the ash and clinker. There were 169,200 cu. yds. of garbage burned in 1899.

Cost of Removing Ashes.—The average cost of removing ashes, exclusive of dump maintenance, at Rochester, N. Y., in 1906, was $0.353 per cu. yd. The average weight of a cubic yard of ashes was 921 lbs. The average cost of maintenance of dumps, ashes, scrapings and sweepings was $0.1073 per team load. A team load weighed 3,683 lbs., the average weight of the wagon being 2,100 lbs.

Cost of Tile Drains.—Clay tiles for drainage purposes are usually round in section, and are usually made in 1-ft. lengths. In soil that can be spaded, a special ditching spade should be used. The blade of this type of spade is narrow and very long (18 ins.), and strongly curved forward to give greater stiffness. With such a spade, a trench 5 ft. deep, and not more than 15 ins. wide at the top, can be dug. Trenches 3 ft. deep are 10 to 12 ins. wide on top, and are taken out in two spadings, or benches. The bottoms of the trenches are shaped so as to fit the tile, by using a tile hoe or scoop

of proper shape, different widths being used for different sizes of tile. The tiles are laid by a man standing on the surface of the ground, using a tile hook for the purpose of placing the tiles in the trench. The trench is backfilled by a team dragging a plow provided with a long evener, so that there is one horse on each side of the trench.

Mr. C. G. Elliott gives the following as the actual cost of draining an 80-acre farm in Illinois:

——Tile.——			——Cost per lin. ft.——			
Size, ins.	Lin. ft.	Depth, ft.	Tile, cts.	Laying, cts.	Total, cts.	Total.
3......	7,030	3	1.32	2.00	3.32	$233.40
4......	8,280	3½	2.00	2.00	4.00	331.20
5......	850	4	3.00	2.42	5.42	46.07
6......	2,700	5	4.00	3.66	7.66	206.82
7......	1,000	5	6.00	3.72	9.72	97.20
Total, 80 acres, at $11.43 per acre..................						$914.69

The cost of "laying," as above given, includes the cost of digging the trench, laying the pipe and backfilling. The men were paid $2 a day, being skilled diggers and tile layers. The soil was a black loam 2½ ft. thick, under which was a yellow clay subsoil.

For tile up to 6 ins. diameter, Elliott estimates 1¼ cts. per lin. ft. for labor of trenching 3 ft. deep and laying the tile; and he allows 0.3 ct. per lin. ft. for backfilling.

The manufacturers of tile do not have uniform list prices from which discounts are given. The following net prices are quoted (1905) for New York delivery in carload lots:

Size of drain tile, ins.	Weight, lbs. per ft.	Net price per ft., cts.
2........................	3	1.45
2½......................	4	1.72
3........................	5	2.18
4........................	7	3.04
5........................	9	3.93
6........................	12	5.38
8........................	19	8.20
10........................	28	14.50
12........................	40	18.80

Tile drains are frequently used for road drainage. In such cases the trench is usually filled part way up with broken stone or gravel, the cost of which must be included in the bidding price per lin. ft. of drain. Tile collars to be used at joints are occasionally specified, but they are of questionable value, and are rarely used in land drainage. On roadwork done by the author, the cost of laying 4-in. tile in a trench was ¼ ct. per lin. ft., exclusive of digging the trench and filling with gravel. The man laying tile received 16 cts. per hr., and he averaged 640 ft. laid per 10-hr. day.

In New Jersey roadwork, where tile drains are used, the 4-in. tiles are frequently specified to be laid on a 1-in. yellow pine plank, 6 ins. wide, in a trench 2 ft. deep. If plank costs $20 per M delivered this item adds 1 ct. per lin. ft. The average bidding price in New

Jersey has been about 12 cts. per lin. ft. for a 4-in. tile drain complete.

Weight of Drain Tile.—Porous or farm tile laid 3 or 4 ft. deep on one or both sides of the roadway is the best method of securing underdrainage for highways. Tile may be had from 3 to 30 ins. in diameter. The smaller sizes are usually 1 ft. long and the larger sizes are 2 or 2½ ft. long. The accompanying table shows the weight per foot and the average carload for various sizes of tile:

	Weight per ft., lbs.	Av. carload. No. pieces.
4-in. tile	6	6,500
5-in. tile	8	5,000
6-in. tile	11	4,000
7-in. tile	14	3,000
8-in. tile	18	1,200
10-in. tile	25	800
12-in. tile	33	500
14-in. tile	43	400
15-in. tile	50	300
16-in. tile	53	250
18-in. tile	70	200
20-in. tile	83	166
22-in. tile	100	160
24-in. tile	112	150
30-in. tile	192	65

Prices of Tile Drains in Place.*—Table III was compiled by Mr. George M. Thomson, County Surveyor of Green County, Iowa, to facilitate the making of estimates on county ditches. Mr. Thomson writes us that the table agrees very closely with bids received during the last two years for doing such work in Greene County. The prices given in the table are for excavating the trench, laying the tile and refilling the trench. The prices given are per foot deep and rod long. For instance, suppose the drain is to be 7.15 ft. deep and is to be laid with 12-in. tile. In the column under 7 ft. and opposite 12 ins. will be found 40 cts., the price per foot deep; then 7.15 × 40 = $2.86, the price per rod for 12-in. tile laid 7.15 ft. deep.

Cost of Digging a Trench and Laying Tile Drain.†—In laying some tiles for the drainage of a wagon road a trench 2 ft. wide on the top and 1 ft. on the bottom, with an average depth of 3 ft., was excavated. The tiles used were 4-in. and 8-in. They were laid in the trench and broken stone placed around them, and over them, before backfilling the trench. This allows the water to enter the tiles much easier than when dirt is put around them. In all, 7,500 lin. ft. of trench was dug.

There were excavated 1,250 cu. yds. from the trench, 75 cu. yds. being rock. The rock was all in the bottom of the trench, sometimes running across the bottom, while in some places it was only found on one side of the trench. Some of it was loosened with bars and picks, but the most of the rock had to be blasted. The rock excavated was broken up by hand into about 2-in. ring stone, and

---

**Engineering-Contracting*, Jan. 22, 1908.

†*Engineering-Contracting*, Sept. 16, 1908.

TABLE III.—EXCAVATION TABLE FOR MAKING ESTIMATES ON DITCH WORK.

	———Average Depth in Feet.———										
Size of Tile.	5 ft.	6 ft.	7 ft.	8 ft.	9 ft.	10 ft.	11 ft.	12 ft.	13 ft.	14 ft.	15 ft.
5 and 6-in.	$ .15	$ .18	$ .20	$ .25	$ .30	$ .35	$ .40	$ .45	$ .50	$ .55	$ .60
7-in.	.18	.20	.25	.30	.35	.40	.45	.50	.55	.60	.65
8-in.	.20	.25	.30	.35	.40	.45	.50	.55	.60	.65	.70
10-in.	.35	.30	.35	.40	.45	.50	.55	.30	.65	.70	.75
12-in.	.30	.35	.40	.45	.50	.55	.60	.65	.70	.75	.80
14-in.	.35	.40	.45	.50	.55	.60	.65	.70	.75	.80	.85
15-in.	.37	.42	.47	.52	.57	.63	.67	.72	.77	.82	.87
16-in.	.40	.45	.50	.55	.60	.65	.70	.75	.80	.85	.90
18-in.	.45	.50	.55	.60	.65	.70	.75	.80	.85	.90	.95
20-in.	.50	.55	.60	.65	.70	.75	.80	.85	.90	.95	1.00
22-in.	.55	.60	.65	.70	.75	.80	.85	.90	.95	1.00	1.05
24-in.	.61	.66	.71	.76	.80	.85	.90	.95	1.00	1.05	1.10
26-in.	.67	.72	.78	.83	.88	.93	.98	1.03	1.08	1.13	1.18
28-in.	.73	.78	.83	.88	.95	.98	1.03	1.08	1.13	1.18	1.23
30-in.	.78	.83	.88	.93	.99	1.03	1.08	1.13	1.18	1.23	1.30
32-in.	.85	.90	.95	1.00	1.05	1.10	1.15	1.20	1.25	1.30	1.35
34-in.	.90	.95	1.00	1.05	1.10	1.15	1.20	1.25	1.30	1.35	1.40
36-in.	.95	1.00	1.05	1.10	1.15	1.20	1.25	1.30	1.35	1.40	1.45
38-in.	1.00	1.05	1.10	1.15	1.20	1.25	1.30	1.35	1.40	1.45	1.50
40-in.	1.10	1.10	1.15	1.20	1.25	1.30	1.35	1.40	1.45	1.50	1.55

was used around the tiles, very little stone being purchased for this purpose.

The wages paid on the job for a 9-hr. day were $3.50 for foremen, $1.35 and $1.40 for laborers, and 75 cts. for water boys. One foreman and one gang of 16 men worked for 9 days, and the job was completed by 2 foremen and 26 men, working 10 additional days.

The total labor cost for excavating the trench, breaking up the stone, laying the tile, and placing broken stone around it, and backfilling the trench was $674.15, or 52 cts. per cu. yd. of trench.

The tile laying was done by one man and an assistant, who wheeled the tiles and laid them alongside of the trench, the tile layer then placing them. These two men, in a half day, could lay tiles in the trench that the entire gang had dug during a day. After they had laid the tiles, with the assistance of a few additional men, they did the backfilling of the trench. The labor cost of placing the tiles was $26.14, making a cost of 0.35 ct. per lin. ft. The cost per lin. ft. for excavating, breaking rock and backfilling was 8.6 cts., making a total cost per lin. ft. of the completed drain of about 9 cts.

Cost of Farm Drainage.—Several excellent articles on the methods and cost of farm drainage appeared in *Engineering-Contracting*, Dec. 4, 1907, Oct. 21, Nov. 4 and Nov. 18, 1908, Oct. 13 and Oct. 20, 1909. These articles occupied about 25 pages, of which the following is a very brief summary.

Mr. L. G. Hicks states that, in draining a farm near Omaha, the cost of tile drainage was $23 per acre. Wages were $1.50 per 10-hr. day and board, the board amounting to $0.50, making a total of $2 per day. Material was black loam, which cost 21 cts. per cu. yd. to excavate from ditches 3½ ft. deep and 12 to 15 ins. wide. The ditch was shaped up with a tile spoon, at a cost of 2¼ cts. per lin. ft., which is equivalent to adding another 20 cts. per cu. yd. The backfilling was done by two men and two horses with a plow at a cost of 1 ct. per cu. yd. Hence the total cost was 42 cts. per cu. yd. The cost of laying the tile was as follows:

	Per 100 ft., cts.
3 or 4-in. tile	5
6-in. tile	6.7
8-in. tile	10

With a tile hook a man lays 100 ft. of 3-in. tile in 15 mins., or at the rate of 4,000 ft. per day.

The cost of this work on a 75-acre farm where 25,150 lin. ft. of tile were laid was:

	Per acre.	Per lin. ft., cts.
Surveys	$ 1.45	0.43
Labor	12.82	3.82
Material	8.55	2.55
Total	$22.82	6.80

A 476-acre "experimental farm" in Minnesota was drained, using 4, 6 and 8-in. tile. Farm laborers received $2 a day, and team with

driver was rated at $4.50 per day. The cost of loading, unloading and hauling was 80 cts. per ton for the first mile, plus 30 cts. per ton for each additional mile, load averaging 2¼ tons over ordinary fields. The contract price for trenching (by hand), tile laying and backfilling was $2.42 per 100 lin. ft. of trench 3 ft. deep, plus 6 cts. for each additional foot of depth. The average trench work done by one man, at $2 per day, was:

	Lin. ft.
3-ft. trench	100
3.5-ft. trench	95
5-ft. trench	80

After a man had acquired some experience, 4 to 6-in. tile were laid with a tile hook at the rate of 2,000 ft. in 10 hrs., where the trench was in good condition and the tile convenient.

After the tile were laid they were covered with earth 4 to 6 ins. deep, called "blinding." A man astride of the trench cuts off earth from each side with a tile spade. This blinding is done at the rate of 4,000 ft. in 10 hrs. The blinding holds the tile in place.

The backfilling was done in three ways: (1) By hand; (2) by drag scraper; (3) by plow and road machine. The costs were as follows:

A trench 3 ft. deep was backfilled by hand at a cost of $0.56 per 100 lin. ft., wages being $2.00 per 10-hr. day.

A trench 3½ ft. deep was backfilled by a drag scraper, two horses and two men, for $0.60 per 100 lin. ft. of trench.

A similar trench was backfilled for $0.32 per 100 lin. ft., using a plow first and a road machine afterward. Two teams and drivers were used on the plow, one team on each side of the trench. A long evener was used, and the plow shifted as desired. After two round trips, the same gang completed the filling by means of a road machine.

In Illinois the average depth to lay tile is about 3 ft., and the distance apart of lateral drains is about as follows:

	Ft. apart.
Light, sandy soil	150 to 300
Heavy loam	75 to 150
Gumbo	30 to 100

The cost in dollars per acre for tile drains may be roughly estimated by dividing 1,500 by the distance apart (in feet) of the lateral drains. Thus, if the drains are 150 ft. apart, the cost per acre is $1,500 \div 150 = \$10$.

In Utah, 40 acres of irrigated farm land were drained, using 4, 5 and 6-in. tile, laid 4 to 5 ft. deep. The cost was $13.50 per acre. There were 5,300 lin. ft. of tile used, at the following average cost:

	Per 100 lin. ft.
Tile	$ 6.40
Laobr	3.80
Total	$10.20

Mr. Jas. T. Taylor gives the following relative to pipes laid in 1891 for irrigating 4,200 acres in the Alessandro District, California.

The pipes were vitrified sewer pipes and cement pipes, 6 to 12 ins. diam., and these pipe lines, including trenching, etc., cost $76,300 for 40 miles of pipe, or $18.15 per acre for the lateral system. This is equivalent to 50 ft. of lateral pipe per acre, at an average cost of 36 cts. per ft. laid.

Cost of Tile Trenching With a Machine.*—A machine made by the Buckeye Traction Ditcher Co., of Findlay, Ohio, was used on the Northwest Experiment Farm, University of Minnesota, in 1902. The machine dug a trench 14½ ins. wide and 4½ ft. deep. It had an 8-hp. boiler and consumed 450 lbs. of coal and 4 bbls. of water per day. It dug 34,000 lin. ft. of trench in 45 days actual working time, or 744 lin. ft. per day. The men who handled the machine were inexperienced.

The following was the cost:

	Per 100 ft.
Labor running machine	$0.45
Coal at $7.50 per ton	0.19
Water	0.13
Oil	0.01
Repairs	0.13
Total ditching	$0.91
Laying tile	0.18
Blinding	0.05
Incidentals	0.09
Total	$1.23

The price of the machine was $1,400.

Although the machine was not well handled and had not at that time (1903) been perfected, it made a very creditable record of cost, as contrasted with hand work, for the latter cost $3.88 per 100 lin. ft. on the same farm.

Two men operated the machine.

I recently saw a machine of the same make and size on a farm in New Jersey where it was averaging 2,000 lin. ft. of trench (15 ins. x 3 ft.) in 10 hrs.

Cost of Laying Small Gas Mains on Six Jobs.†—Mr. W. H. Matlack is author of the following:

In this article the cost is given of laying 4-in., 6-in. and 10-in. gas mains on 6 different jobs, there being a total of 10,924 lin. ft. of pipe laid. The 10-in. main was first laid, the 6-in. and 4-in. following. The work was done in the months of May and June, 1908. The weather during that spring was unusually wet and all costs are a little higher than they should be, yet the tables will give a fair idea of what work will cost under such conditions.

The ditch averaged 3 ft. 6 ins. in depth and was 28 ins. wide. The soil was half and half sandy clay and gumbo, with the exception of about 150 ft. of quicksand encountered in laying the 10-in. line. The 10-in. line was almost all laid on rainy days in a wet

*Engineering-Contracting, Nov. 4, 1908.
†Engineering-Contracting, March 31, 1909.

ditch. From 1,500 to 2,000 ft. of the ditch were one-third full of water at one time, which caused it to cave, and about 900 ft. had to be redug, aside from bailing the water with buckets from some 2,000 ft. of it.

A creek was crossed with the 10-in. line. Here lead joints were used, but all other joints on the six jobs were made with cement. The following fittings were put in on the 10-in. line: Three 10-in. drips, thirteen 5-in. tees, one 10-in. cross, and one 10 x 16-in. reducer.

The 6-in. line No. 1 was laid next and under similar conditions, and the following fittings used: Three 6-in. crosses and three 6 x 4-in. tees.

The 4-in. lines were put in when the weather was good and the soil dry. Records kept in laying the 4-in. pipe showed that 3 ft. of yarn would make four joints and that one sack of cement would caulk and cap 32 joints. Lehigh Portland cement was used, and tests previously made showed tensile strengths of from 500 to 600 lbs., per sq. in.

The gang averaged 25 men. The best day's work consisted of 52 lengths of 6-in. pipe and 29 lengths of 4-in. pipe, the ditch being opened, pipe laid and caulked in 10 hours. In backfilling the trench the earth was hand tamped in from 6 to 8-in. layers. The team was used in handling pipe and other supplies from the plant to the job, an average distance of two miles.

The following wages were paid: Foreman, 27½ cts. per hour; caulkers, 22 to 25 cts. per hour; laborers, 17 cts.; team and driver, 45 cts.; watchman, 17½ cts., and water boy, 15 cts. per hour. A night watchman was employed throughout the job and a man for Sundays.

The cost of the work, divided into various items of labor for each lineal foot, is as follows:

Job No.	"A"	"1"	"2"
Size	4-in.	6-in.	10-in.
Total ft. laid	1,412	1,302	5,781
Team and driver	$0.007	$0.014	$0.023
Foreman	0.007	0.005	0.007
Superintendence	.....	0.005	0.007
Excavation	0.040	0.033	0.058
Caulking	0.004	0.007	0.012
Backfilling	0.040	0.032	0.058
Sundry expenses	.....	0.002	0.006
Total cost per ft.	$0.998	$0.096	$0.171

Job No.	"B"	"C"	"D"
Size	4-in.	6-in.	6-in.
Total ft. laid	595	841	993
Team and driver	$0.009	$0.011	$0.120
Foreman	0.009	0.003	0.150
Superintendence	.....	0.005	.....
Excavation	0.052	0.409	0.500
Caulking	0.007	0.009	0.110
Backfilling	0.050	0.125	0.137
Total cost per ft.	$0.127	$0.125	$0.137

The sundry expense item is for the watchman and water boy.

All the pipe was tested before going into the ditch and all leaky joints were cut out and redriven. There were 18 such joints on the 10-in. line due to rain over night on green joints. After the pipes were all laid they were all tested. The 10-in. line was tested from four parts. The others were tested once. This testing, which was all in the air, was done with an old style hand pump that required 10 men to operate. In testing, 12 men were used, 10 to pump up the line, 1 to snap joints and 1 to look after the gage. The time consumed by a test varied from 45 mins. to 1½ hrs. This time is distributed as well as possible between the laborers and caulkers, as all took a hand.

After completing the work a final test was made, as shown by Fig. 5. The piping was placed and a meter set: the pressure was then equalized by running gas from an old 10-in. line through the 1-in. line and into the new line, this line being opened at *B* for 15 mins. At the end of this time *B* was closed and *A* opened, allowing the gas to pass through the meter and to register. After

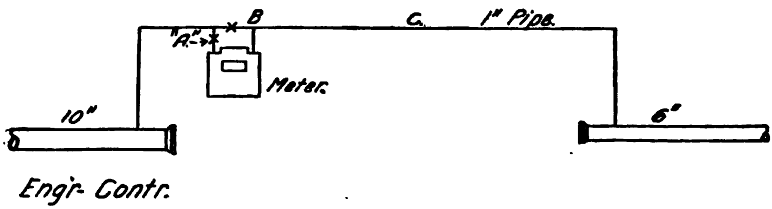


Fig. 5.

the register was made, which took almost 10 mins., the meter was read and noted, then left standing for 2½ hrs. At the end of that time it was reread and finding the reading to be the same as at the time of the first registering, it was known that no gas had passed through the meter, hence there were no leaks in the new line. The following day men were sent along the line and all drip leads were opened, allowing all air to pass out.

Cost of Laying Wrought Iron, Screw-Joint Pipe for Compressed Air Main.—Mr. E. E. Harper gives the following:

The work consisted of laying 7,000 ft. of 8-in. and 4,000 ft. of 6-in. wrought-iron, screw-joint pipe for a compressed air line carrying 80 to 90 lbs. pressure. The work was all performed by common labor, none of the men being experienced in pipe laying.

The greatest cause of delay in laying screwed pipe is the difficulty in getting each successive length of pipe into line and keeping it there until the first threads take hold and the pipe begins to screw together. To overcome this difficulty a cradle for supporting the pipe at the joint, a jack for adjusting and supporting the outer end of the pipe and a straight-edge for lining the pipe were devised. The cradle holds the threaded end of the pipe in position to enter the

sleeve coupling on the last joint laid; the jack allows both vertical and horizontal adjustment of the joint of pipe; and the straight-edge shows when the pipe is in line ready to screw together. The cradle was simply a wood block, 8 x 8 ins. x 24 ins. in length, with a groove having a 4-in. radius cut in its top. The jack is shown by Fig. 6 and the straight-edge by Fig. 7. The movable block on the straight-edge is necessary because it is almost impossible to make a 12-ft. straight-edge that will remain true for more than a day.

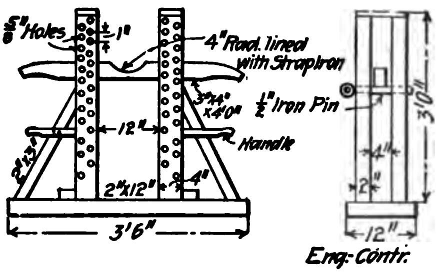


Fig. 6.—Jack.

These devices saved fully 50% over the crude and unsatisfactory method of using blocks to hold the pipe in line. There was no straining and lifting to hold the pipe in place, and as the pipes were started together straight there were no stripped threads and bad joints, and the pipe made up so easily that one man with a pair of 3-ft. tongs often screwed an 8-in. pipe half way up; it was then completed by four men using two pairs of tongs with 8-ft. handles.

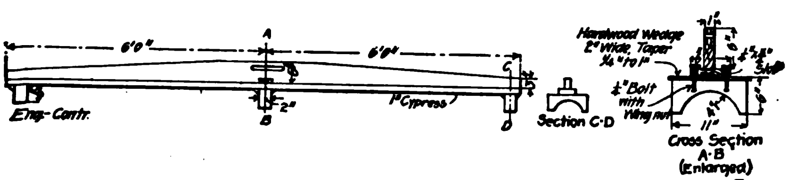


Fig. 7.—Straight Edge.

The threads, both male and female, were cleaned with wire brushes. Dixon's pipe joint compound was used on all screwed joints. Ring gaskets of 1/16-in. Rainbow packing were used on flange joints, the gasket being pasted to one flange with coal-tar roofing paint, which held it in position while the joint was being made.

Six-Inch Pipe Line.—The total length of 6-in. pipe was 4,118 ft. The pipe was 6-in. lap welded casing weighing 15 lbs. per lin. ft.

It was laid with sleeve couplings, 11½ threads per inch, with a flange union every 150 ft. and U-bends for expansion every 500 ft. The average length of joints was 20.1 ft.; an average of 588.2 ft. of pipe or of 29.3 joints, was laid per 10-hr. day. The best day's work was 1,065 ft., or 53 joints, with 6 men working 9 hrs., making 177.5 ft. per man; the poorest day's work was 120 ft., or 6 joints, by 6 men working 9½ hrs. The work was done from Aug. 15 to 24, 1907, in fair weather except, for one day, when the men worked 4 hrs. in rain and laid 22 joints. The men walked 2½ to 3 miles to and from work. The average gang was: 4.85 men at 20 cts. per hour, 1 foreman at 30 cts. per hour, and 1 waterboy at 10 cts. per hour. The cost of pipelaying was as follows per 100 ft.:

	Per 100 ft.
Clearing right of way	$0.327
Hauling and distributing	1.578
Blocking to grade	0.116
Constructing bents	0.450
Anchors for U-bends	2.290
Painting	0.900
Tools	0.100
Testing	0.300
Laying	3.137
Surveying and superintendence	0.700
Total	$9.898

The total cost per foot exclusive of cost of pipe was 9.898 cts. or, say, 10 cts. The following notes explain the work included in the various items:

Clearing.—Removing small brush for a width of 10 ft.

Hauling.—The average hauls were 3,000 ft. over bad roads, steep and rough. This item includes loading pipe on cars and unloading, hauling and distributing, including seven U-bends. Teams and drivers got $3 per day.

Blocking.—Includes temporary blocking and bending pipe in five places by building fires on it.

Anchors for U-Bends.—Includes 8 piers at $12 each, including bolts and clamps.

Bent Construction.—Includes carpenter work only on about 20 bents, averaging 3 ft. in height and made 4 x 6-in. stuff.

Painting.—Includes cost of painting and cleaning pipe with wire brushes with paint costing $1 per gallon and labor at 20 cts. per hour. The pipe was painted one coat.

Tools.—Includes shopwork and depreciation.

Eight-Inch Pipe Line.—The total length of 8-in. pipe was 7,101 ft. The pipe was 8-in. O. D., lap-welded casing weighing 20 lbs. per foot, laid with sleeve couplings, 11½ threads per inch. The average length of joints was 19.15 ft. There was a flange union every 150 ft., and U-bends for expansion every 600 ft. An average of 503.6 ft. was laid per day, of 10 hrs., or 26.3 joints. The best day's work was 613 ft., or 32 joints, by 6 men, including foreman; the poorest day's work was 380 ft., or 20 joints, by 7 men, including foreman. The work was done from July 2 to Aug. 5, 1907, the weather being

hot and sultry, the thermometer ranging from 85° to 100°, and averaging 90° in shade. The average gang was: 5.92 men at 20 cts. per hour, 1 foreman at 30 cts. per hour, and 1 waterboy at 10 cts. per hour. The cost was as follows per 100 ft.:

	Per 100 ft.
Surveying and superintendence	$ 1.000
Laying	3.580
Clearing	0.187
Hauling and distributing	1.032
Blocking to grade	1.110
Constructing bents	1.069
Anchors for U-bends	2.535
Painting	1.200
Tools	0.102
Testing	0.388
Total cost of laying	$12.203
Cost of pipe	76.400
Grand total cost	$88.603

The total cost per foot, exclusive cost of pipe, was thus 12.2 cts., and including cost of pipe 88.6 cts. The following notes explain the work included in the various items:

Clearing.—Removing small brush for a width of 10 ft.

Hauling.—Includes 12 U-bends, which cost $1 each to haul; teams and drivers, 30 cts. per hour; laborers, 20 cts. per hour, and foreman, 30 cts. per hour.

Bent Construction.—Includes carpenter work only on about 80 bents of 4 x 6-in. stuff, spaced 30 ft. apart and ranging in height from 1 ft. to 16 ft., averaging 6 ft. high.

Anchors for U-Bends.—Includes 12 piers at $15 each, including bolts and clamps.

Painting.—Same as for 6-in. pipe.

Testing.—Includes laying and connecting 200 ft. of 4-in. pipe to pump line. Tested to 110 lbs. hydraulic pressure. Leaks developed in two tees in line and these were repaired, line tested again and found tight. The pipe cost $76 per ton (100 ft.) f. o. b. McKeesport, and the freight to Flat River was 40 cts. per ton.

Cost of Maintaining Teams.—I have maintained teams at the following cost per month per team of two horses:

½ ton of hay, at $10	$ 5.00
30 bu. oats, at 35 cts.	10.50
Straw for bedding	1.00
Shoeing and medicine	2.00
Total	$18.50

A generation ago there were 2,000 horses used on the Brooklyn street railways. The cost of feeding each horse was $10 a month, and the depreciation in value of each horse was 25% per annum.

Contract work is not so severe as street car work; still the annual depreciation is probably not less than 15%. A team, wagon and harness costing $300 should be charged with about $60 per annum for interest and depreciation. When the team is working it must be fed oats, when not working it can be fed on hay at half the usual cost.

The following gives the average feed of horses and mules used by the H. C. Frick Coke Co., extending over a period of 6 years: 500 lbs. of hay, 7 bus. of oats, 4 2/5 bus. of corn on the ear per head per month. The daily feed of each animal was two feeds of corn, 13 ears to the feed (70 lbs. per bu.), one 6-qt. feed of oats, and about 16½ lbs. of hay. Each animal averaged about 13 miles traveled per day underground, 15 miles being the maximum 10-hr. day's work.

It is not ordinarily possible to get more than 180 days of work per annum out of a contractor's team in the North, and very frequently much less. We may, therefore, say that $1.50 for each day actually worked by the team will cover its feed, interest and depreciation, for the year. If the driver is paid only while at work, then his $1.50 added to that of the team makes $3 a day for each day worked.

The cost of feeding 25 horses at work building roads near San Francisco, for a period of 12 mos., was as follows, per horse per day:

28 lbs. wheat hay, at $15.50 per ton	$0.215
12 lbs. rolled barley, at $24.10 per ton	0.150
1½ lbs. oats, at $27.40 per ton	0.020
¼ lb. bran, at $21.20 per ton	0.003
1½ lbs. straw bedding, at $13.80 per ton	0.009
Wages, 1 stableman ($775 for year), and hauling forage ($281 for year)	0.113
Total per horse per day	$0.510

The above shows a consumption of nearly 42 lbs. of feed per horse per day, which seems large, but is not excessive for heavy draft horses working daily. A conservative estimate of the food waste is 5%.

A four-horse team averaged 16½ miles traveled per day over fair macadam roads with some 5% grades. The load was 3 short tons, plus the 0.65-ton wagon; and the haul, one way, was ½ to 1 mile.

Cost of Horse Maintenance.*—In a report to the Street Cleaning Department of Boston, Mass., Mr. Richard T. Fox, Sanitary Expert, Chicago, Ill., gives some figures as to the stable and yard expenses of that department for 1906. The following matter has been taken from that report. The street cleaning department owns 128 horses, which are used for driving purposes for machine sweeping and the removal of street dirt. Of these horses 95 are maintained directly by the department and 33 are boarded by the Sanitary Department. The net cost in 1906 for rent, repairs, shoeing, veterinary services, medicines and feed for the 128 horses amounted to $66,283. The cost per horse per year is therefore $517.83 or $43.15 per month. As a comparison Mr. Fox found that the S. S. Pierce & Co., wholesale grocers of Boston, paid $27.65 per horse per month for maintenance, the cost including shoeing, veterinary service and boarding in a public stable. Mr. Fox considers that $19 per month is a fair average yearly price per horse, if maintained at private

**Engineering-Contracting*, Nov. 13, 1907.

expense. The horse shoeing bill for the Street Cleaning Department amounted to $33.43 per year per horse or $2.78 per month. The veterinary services and medicine amounted to $17.97 per horse per year. In comparison with this Mr. Fox found that S. S. Pierce & Co. pay a little less than $12 per year for veterinary service and medicine; the Boston Fire Department pays $12 per year per horse, and the Knickerbocker Ice Co., Chicago, Ill., pays $5 per year per horse.

Cost of Maintaining Horses, New York City.*—A report made by the Parsons-Herring-Whinery Commission on the cost of municipal street cleaning contains data on horse maintenance, of which the following is a brief summary. The cost of maintaining each of 1,174 horses for one year (1906) in Manhattan and The Bronx was:

Stable rental	$ 41.44
Labor at stables (hostlers at $720 yr.)	237.00
Feed and bedding	171.00
Shoeing	18.36
Veterinary	5.63
Total, at $1.30 per day (365 days)	$473.43

The commission states that private corporations in New York City pay about $330 per year per horse for the same maintenance that costs the city $473.

Feed for Street Car Horses.—The daily mileage of street car horses, working in teams, is 15 miles traveled in 3 hrs. In cool weather this mileage may be covered in one trip, but in summer the time should be divided. For this sort of work a horse weighing about 1,100 lbs. is best.

A weekly report of feed should show.

	Used during week.	On hand.
Hay	....	....
Straw	....	....
Corn	....	....
Oats	....	....
Bran	....	....
Salt	....	....
Proportion of feeding		....
Average number of horses		....
Pounds of hay and meal per horse		....
Remarks		....
Required during week		....

In Brooklyn the old horse car companies prescribed the following feed per horse:

In summer, 15 lbs. of mixed grain ground (5 lbs. corn, 10 lbs. oats). In winter, 10 lbs. corn and 5 lbs. oats. About 15 lbs. of cut hay moistened and mixed with the meal. About 4 lbs. of cattle salt to each 100 horses. Hours for feeding, 5:30 and 10 a. m. and 4 p. m. Quantities at each feed, 10.8 and 12 lbs. respectively. Road mileage, 16 miles per day; rest Sunday. Average working life (based on 20 years experience) 7 years.

***Engineering-Contracting,* May 20, 1908.

In Providence, R. I., about 35 lbs. of straw for bedding required per horse per month. Horses in groups of 16 under the care of one stable man, who also harnesses them.

Cost of Maintaining Farm Horses and of Raising Hay and Oats in Minnesota.*—The following data should be of value both to the highway engineer, for estimating the cost of hauling, and to the contractor who may wish to raise feed for his horses. The data have been abstracted from bulletins Nos. 48 and 73 of the U. S. Department of Agriculture, entitled "The Cost of Producing Minnesota Farm Products." The bulletins contain very complete summaries of the results of careful investigations during the years 1902 and 1907 inclusive, covering about 70 farms in five counties of Minnesota. These bulletins mark the beginning of the scientific application of cost analysis to farming, and, so far as we know, are the only records of their kind in print.

The first step in ascertaining the cost of producing crops is to determine the cost of a horse hour and of a man hour. To do this the "route statisticians" (assisted by the farmers) kept accurate records of the number of hours that each horse was actually worked each day, as well as the number of hours worked by each man.

For the purpose of condensing the results, while at the same time giving the data in considerable detail, we have selected the records of Rice county, where 24 farms of about 170 acres each were recorded. There were 5.4 work horses (not including colts or driving horses) per farm. The time of the farm owner was counted as being of no more value than of his hired men. The following is the average number of hours worked per day during the years 1902 to 1907, including the time of the farm owner:

	Week Days.		Sunday.
	Man.	Horse.	Man.
January	6.80	1.16	4.85
February	6.62	1.14	4.80
March	7.57	1.34	4.63
April	9.88	4.54	4.02
May	9.03	4.00	3.46
June	9.64	3.11	3.11
July	9.32	3.44	2.82
August	10.25	4.78	2.66
September	11.03	4.07	2.93
October	9.56	3.86	2.84
November	9.08	3.05	3.55
December	7.29	1.55	4.57
Average	8.94	3.03	3.64

On 20 farms in Lyon county (averaging 250 acres each) there were 6.8 work horses per farm; and on 18 farms in Norman county (averaging 210 acres each) there were 7 work horses per farm; and the average number of hours worked was as follows:

	Lyon.	Norman.
Per week day per man	8.66	8.10
Per week day per horse	3.29	3.14
Per Sunday per man	3.05	2.76

Engineering-Contracting, June 2, 1909.

It would appear that the Sunday work consisted mainly in caring for the stock and milking the cows. There were about 12 milch cows per farm.

If the 3.64 hours of Sunday work represents the average daily time spent caring for the stock, etc., it would seem that this accounts in large measure for the small number of hours worked daily by each horse. Nevertheless, there is a surprising loss of horse time. According to the bulletins, this is in part due to the practice on many farms of having from "one to three unnecessary horses," kept "mainly that they may be available during a few days when the crops were being harvested."

In round numbers, we may say that each horse averaged only 1,000 hrs. worked per year, which is equivalent to 100 days of 10 hrs. each. The cost of feeding horses averaged $65 per year (1905-1907) in Rice county, $55 in Lyon county, and $43 in Norman county. The detailed cost of the feed in Rice county was as follows per horse during 1905 to 1907:

Grain for 4 winter mos., 1,477 lbs. at 0.7 ct.	$10.38
Hay for 4 winter mos., 1,924 lbs. at 0.27 ct.	5.34
Grain for 8 active mos., 3,736 lbs. at 0.88 ct.	33.05
Hay for 8 active mos., 5,149 lbs. at 0.31 ct.	16.21
Total, 12,290 lbs.	$64.98

The prices for grain and hay were the local market prices less the cost of hauling from the farm to the market. The grain was oats, barley and corn, weighing 32, 48 and 56 lbs. per bushel, respectively. Oats at 0.88 ct. per lb. is therefore equivalent to 27½ cts. per bushel. During the years 1905 to 1907, the average farm prices of farm products throughout Minnesota were as follows: Oats, 31 cts.; barley, 45 cts.; corn, 39 cts.; hay, $6.27.

The feed per horse per day was as follows in Rice county:

	Winter season. Lbs.	Active season. Lbs.
Grain	12.1	15.4
Hay	15.8	21.2
Total	27.9	36.6

No account was kept of pasturage nor of any straw fed to horses. It is not clear whether the lower price (0.7 ct. per lb.) for grain in the winter season was due to feeding corn instead of oats, or not. It should be noted that the feed during the winter season cost $3.93 per horse per month as compared with $6.18 per month during the active season. In Norman county the cost of feed was much lower, due to the practice of feeding very largely with straw in the winter months. The extent to which this was done is well shown by the following records per horse per day in Norman county:

	Winter season. Lbs.	Active season. Lbs.
Grain	6.0	11.4
Hay	6.4	23.4
Total	12.4	34.8

The average annual cost of maintaining a horse in Rice county was estimated as follows:

	Average for 1904 to 1907.	For 1907.
Interest on horse at 5% on depreciated value	$ 5.54	$ 6.74
Depreciation (too low)	5.56	4.35
Harness depreciation	2.10	1.39
Shoeing	1.42	1.46
Feed	63.49	75.03
Labor	11.88	15.01
Miscellaneous	0.40	0.29
Total	$90.40	$104.27

The item of interest is estimated on the average depreciated value of the horse; thus a horse worth $220 in its prime (4 yrs. old), has a working life of 10 to 15 years, and at the end of that time is worth nothing, hence the interest is estimated on its average depreciated value of $110.

The bulletin states that the annual depreciation of $5.56 is too low for an average, and is due to the fact that the increase in the market prices of horses has offset largely the actual depreciation. This method of accounting is fallacious, for fluctuating market values should not be allowed to affect the depreciation charged off annually, for this depreciation charge is really a sinking fund charge intended to return the original investment at the end of the life of the animal. If a $150 horse has an average working life of 10 years, $15 should be charged off each year for depreciation, which is $9.44 more than the average depreciation charge above given. An item that has been entirely omitted is the cost of sheltering. The bulletin estimates this item at about $6 a year for each cow, which covers its pro rata share of interest, insurance, depreciation and repairs on a barn costing $80 per head housed. If we add the $9.44 and the $6 to the $90.40 above given, we have a total of $105 as the average cost of maintaining a horse during 1904 to 1907. The corresponding cost for 1907 would be nearly $120. Hence, on the basis of 1,000 hours worked annually, the cost of maintenance was 12 cts. per horse per hour in Rice county in 1907. Including cost of housing and a fair allowance for depreciation, there was no county where the average annual cost of maintenance fell below $100 per horse in 1907. Regarding the assumed depreciation of 10 per cent per year, the bulletin says:

"The experience of many farmers would incidate that the average working life of a farm horse is ten years."

It will be remembered that the feed was charged at its market value less the cost of hauling to market. Strictly speaking this is not correct, but the feed should be charged at its actual cost of production. This cost will next be considered, but, before doing so, it is desirable to record the cost of hired farm labor in Minnesota.

The average monthly cost wage during the "crop season" (8 mos. April 1 to Nov. 31) was $26.16 in Rice county during 1905 to

1907, to which must be added the cost of board, which was $14.36, making a total of $40.50. During the four winter months (Dec. 1 to Mar. 31), the cash wage was $15.80. This makes an average wage, including board, of $37 per month throughout the year, or $444 for the year. As above given, the total number of hours worked per man, including Sundays, was nearly 3,000 hrs. per year. Hence the cost of regular hired farm labor was nearly 15 cts. per hr. in Rice county. The average for the three counties was 12 cts. per hr. In 1907, the cost of board was $2 more per month than the average of the years 1905 to 1907 in Rice county.

In addition to the regular hired men on each farm; a number of men are employed by the day during the active season, and in 1907, these men received 20 to 25 cts. per hr. including board. Unfortunately no record is given of the percentage of men thus employed by the day, so that it is impossible to state accurately what was the average wage paid to all men, including both classes.

With wages of regular hired men at 15 cts. per hr. worked, and cost of horses at 12 cts. per hr. worked, the cost of team and driver was 39 cts. per hr. in Rice county in 1907, and in no county was it less than 30 cts. It may fairly be assumed to have averaged (in all counties) at least 35 cts. per hr. worked in 1907. If men hired by the day were employed as drivers, the cost was 40 to 45 cts. per hr. for team and driver. These data dispose of Prof. Ira O. Baker's contention that team time on a farm is worth only a fraction of the ordinary rates at which teams are usually hired.

As above stated, the cost of board in Rice county averaged $14.36 per month per man in 1907, or $172 per year, or 47 cts. per day. It is not given in detail for any particular county, but the following are typical examples of the daily cost of board on two farms in 1905:

	No. 1.	No. 2.
Food	$0.181	$0.190
Fuel and light	0.041	0.027
Labor (woman at $20 per mo.)	0.171	0.120
Labor (man at about $35 per mo.)	0.019	0.012
Total	$0.412	$0.349

The higher cost on farm No. 1 is due to the fact that the average number of men boarded was only 3½ as compared with 5 on farm No. 2, thus increasing the daily cost of the labor of household work charged to each man's board.

The cost of producing various crops is given in the bulletin, but unfortunately only the average cost for the period of 1902 to 1907 is given, and not the cost for 1907 also, for wages and prices were considerably higher in 1907, and seem likely to remain so. The costs are given in terms of the acre as the unit, but, as the average amount of product per acre is also given, we can arrive at the cost per bushel or ton. Interest on the land, at 5

per cent, is properly included as a part of the cost. The following is the average cost per acre of hay in Rice county:

	Per acre.
Seed	$0.292
Mowing (first crop)	0.368
Raking (first crop)	0.178
Cocking and spreading (first crop)	0.199
Hauling to barn (first crop)	1.099
Mowing (second crop)	0.264
Raking (second crop)	0.115
Cocking and spreading (second crop)	0.150
Hauling to barn (second crop)	0.460
Machinery, interest, deprec. and repairs	0.548
Land rental ($70 at 5%)	3.500
Total	$7.178

The cost of the seed per acre was determined thus:

8 lbs. timothy at 3 cts.	$0.24
4 lbs. clover at 16 cts.	0.64
Seed for 3 yrs. at $0.293 per year	$0.88

To the above total of $7.18 per acre should be added about $1 for general expense, according to the bulletin, which would give a grand total of $8.18 per acre of hay. The average yearly production of hay (two crops) was 2.25 tons per acre in Rice county, hence the cost was $3.64 per ton. The average for three counties was 1.85 tons per acre, hence it is safe to say that the cost averaged not far from $4 per ton.

It will be noted that there is no item for plowing, the reason being that the hay seed is sown with the grain crop against which the full cost of plowing, etc., is charged. It may well be questioned whether this is correct accounting. The cost of plowing is $1.25 per acre.

The average farm price for hay in Minnesota was $6.05 per ton during the period of 1902 to 1907.

The cost of producing oats in Rice county during 1902 to 1907 averaged as follows:

	Per acre.
Seed	$0.997
Cleaning seed	0.023
Plowing (in the fall)	1.256
Dragging	0.285
Seeding	0.261
Cutting	0.401
Twine	0.335
Shocking	0.165
Stacking	0.772
Stack thrashing (labor)	0.568
Thrashing (cash cost)	0.774
Machinery, interest, deprec. and repairs	0.517
Land rental ($70 at 5%)	3.500
Total	$9.854

To this should be added about $1 for general expense, making a grand total of $10.85 per acre. The average production in Rice county was 41 bu. per acre; hence the cost was nearly 26½ cts. per bushel. The average price of oats in Minnesota was 29.2 cts. per bushel during 1902 to 1907.

The bulletin does not give the average wage paid during 1902 to 1907, but it gives enough data to enable us to say that it was about 12½ cts. per hr. worked, including board. The cost of a horse averaged about 8 cts. per hr. worked, during the same period, on the basis of depreciation assumed (which was confessedly too low) and without any allowance for cost of shelter. But, making proper allowance for depreciation and shelter, the cost of a horse was about 9 cts. per hr. worked. It is clear, therefore, that a team and driver cost more than 30 cts. per hr. worked, during the period of 1902 to 1907.

It should be noted that the farm owner's time was counted the same as an ordinary farm workman, which, as above stated, was 12½ cts. per hr. Obviously this is a questionable procedure. The farm owner is really a superintendent, even though he works with his men, and he is of a grade of intelligence that would command much higher pay than an ordinary workman. The farm owner really gets his pay in the form of "profits." If proper allowance is made for "supervision," it is evident that the costs above given will be considerably increased—probably by at least 10 per cent.

The permanent value of the data in these bulletins would be much greater were the averages made into a sort of composite picture, giving a typical average farm organization thus:

1 farm-owner.
3 regular hired men.
2 extra men (4 extra for 6 mos.).
5 work horses.
1 woman, household work.

Then the average farm "plant" should be listed, giving prices of each item, including buildings and land, cows, sheep, hogs, etc. Then the total annual product should be itemized, giving actual unit costs per bushel, pound, ton, etc.

Then should follow the unit costs per acre, and these should be tabulated so as to show the amount of work on each item, thus:

	Per acre.
Plowing: 1 team and driver, 4 hrs. at 30 cts......	$1.20
Dragging: 1 team and driver, 1½ hrs. at 30 cts...	0.45

This should be followed by the number of units produced per acre.

The information in these bulletins is excellent, but is not arranged as above indicated, and, therefore, any item of cost on any given farm cannot be compared with another except in terms of dollars and cents, which is often very misleading due to differences in rates of wages. In brief, farm costs should be recorded exactly like engineering construction costs, giving the organization of the working forces, rates of wages, prices of plant, number of hours (or days) of work at stated prices are required to perform each item of work. When recorded in this manner, accurate comparisons are readily made, and correct conclusions drawn.

By way of comparison we add some data taken from the "Encyclopedia Brittanica," under the head of Agriculture. There it is stated that during the 30 weeks of active season on the farm,

each horse is fed 16 lbs. of oats and 24 lbs. of hay per day. The annual cost of maintaining a farm horse is estimated thus:

30 weeks' feed (active season) at $2.75	$ 82.50
22 weeks' feed (inactive season), clover, at $1.25	27.50
Total feed	$110.00
Interest, $200 at 5%	10.00
Depreciation, etc., $200 at 12½%	25.00
Total annual cost	$145.00

The $200 includes not only the cost of the horse, but its pro rata of farm implements. There was about 1 horse for every 30 acres of farm.

It is stated that unmanured land yields (in 1873) 16 bushels of wheat per acre, but that the application of 400 lbs. of guano per acre doubles the yield. In 1873 the average yield in England was 27 bushels of wheat (63 lbs. per bu.) per acre, an increase of 14 per cent over what it had been 80 years before. The present yield (1909) is about 32 bu. of wheat per acre in England.

In 1873 the following were regarded as being "good crops" per acre:

1 ton (2,240 lbs.) of grain plus 2 tons straw.
1 ton of beans plus 1½ tons straw.
8 tons potatoes.
17 tons beets or turnips.
35 tons cabbage.

Cost of Maintaining Mules.—Mr. Chas. E. Bowen gives the following data as to costs in 1906 in Alabama.

A first class mule costs $200. Its useful life is 6 years, at the end of which it will bring $50. The average cost of maintenance in 7 mines was as follows per mule per calendar day:

Food	$0.30
Stableman	0.05
Interest and depreciation	0.10
Total	$0.45

The daily ration was as follows:

	Lbs.
Hay	10
Grain	16
Total	26

The U. S. army ration is 14 lbs. of hay and 9 lbs. of grain for a mule, and 14 lbs. of hay and 12 lbs. of grain for a horse.

Due to holidays, Sundays, etc., about 276 days in the year are worked in the mines, hence if all the mules worked the cost would be 60 cts. per mule per day worked. However, about 10% are idle, due to sickness, etc., so that the actual cost per working animal per day is 66 cts., to which must be added 4 cts. for shoeing and harness, making a total of 70 cts., not including any allowance for stable rental.

Mr. E. Hogg says that a mule weighing 1,000 to 1,100 lbs. eats 12 lbs. of grain and 15 lbs. of the best hay per day. He feeds ⅔ cracked corn and ⅓ oats, and gives bran twice a week.

Shipping Contractors' Horses in Cars.*—We understand that in the northwest the railroads receive from 14 to 16 horses to be shipped in a stock car, charging the minimum shipping weight, 28,000 lbs., or an average per horse of 2,000 lbs. A 30,000-lbs. capacity car, 30 ft. long, would accommodate this number of horses giving them each about 2 ft. of space.

In the south the writer has been accustomed to ship 20 mules in a car paying for the actual weight of the mules. The length of the car would vary from 30 to 33 ft., thus giving a little over 1½ ft. of space to a mule. In a 36-ft. car 21 or 22 mules could be shipped.

In a palace stock car ranging in length from 54 to 57 ft., the writer has shipped 30 mules, thus giving a space of about 1.8 ft. per mule. A few horses were generally shipped with the mules, but horses cannot be crowded as much as mules can, and at times a separate stall must be built for a valuable horse to keep the mules from crowding or injuring it.

In loading mules into a car a well broken horse is frequently a great help, as mules will follow horses as a rule, and by leading in the horse, several mules can be taken into the car right behind him.

Unless shipped in palace stock cars, animals must be unloaded on a long journey once every 24 hours, so as to be fed and watered. The help of a horse in taking the mules in and out of a car is of great assistance, and saves much time. Railroad companies allow at least one care-taker to accompany a shipment of horses or mules, and he is a busy man when the time arrives for feeding the stock.

Hauling Heavy Machinery on Wagons.—In hauling cement and coal to the Spiers Falls Dam from Glens Falls, N. Y., I found the average load was 2 net tons per team of horses. The loads ranged from 3,500 to 4,500 lbs. The haul was 9 miles, one way, and a round trip constituted a day's work. Teamsters were paid by the ton. The road was sandy, but level, except for about half a mile at the end. Two teams were hitched onto a wagon to pull up this hill at the end.

Some very heavy pieces of machinery were hauled on wagons. One piece of machinery weighing 14 tons was slung between two heavy timber beams whose ends rested on bolsters on the wagons. Thus the piece of machinery was really slung between two wagons, one wagon in front and one behind. In order to steer the rear wagon a simple steering gear was made, very much like the steering device for controlling the rudder of a ship. It consisted of a pilot wheel mounted at the forward end of the rear wagon, and a drum from which two ropes passed around pulleys to the stub tongue of the wagon. One man could thus steer the front wheels

***Engineering-Contracting*, Sept. 25, 1907.

of the rear wagon. With 12 horses this 14-ton load was hauled over the sandy road.

A heavier load, 28 tons, was not loaded on wagons, but was hauled on rollers, a temporary timber way being laid in front of the rollers, as in house moving. It took 12 teams 9 days to haul this load the 9 miles.

Handling Teams With a Jerk Line.*—Mr. W. A. Gillette is author of the following:

I have been especially impressed with the difference between the extreme West and East in handling teams. When I did construction work in the East, I did as Easteners do, namely, submitted to the dictation of teamsters in the determination of each driver to drive his own team. Consequently, when we wanted to use three or four teams on a road grader or plow, three or four teamsters walked along, not driving but "herding" the teams. Once in a while we could find a man who could drive four horses, but not often; and, when he knew how, he wouldn't do it.

Consider what it means to a contractor to have three extra drivers on a plow, drawn by four teams and two extra drivers on a road grader drawn by three teams. It is just as ridiculous as having two men loading wheel scrapers. Five extra men on an outfit as mentioned above means $7.50 a day, drivers' wages being $1.50 a day.

In the West we use one driver for one, two, three, four, five or more teams, and these drivers will handle three, four or more teams with one rein or jerk line with as much ease as the ordinary driver handles one team. It is a comparatively simple matter to train these teams to respond to a jerk line, and to the shout of "gee" or "haw."

For the benefit of those who do not know how to hitch a jerk line, I will explain. It is customary to use a strong braided clothes line. This line reaches from the "nigh" wheel animal to the "nigh" lead animal, and is fastened to the left hand side of the bit; from this main line a short piece of the line passes under the jaw to the right side of the bit, making a "Y." Fastened to the hames on the right side of the "nigh" lead is a "jockey stick" (a short piece of wood or iron) which reaches to a curb strap fastened to the bit of the "off" lead animal. A straight pull on the jerk line pulls the "jerk" line or "nigh" animal to the left, or "haw," and the "jockey stick" guides the "off" animal. A succession of jerks on the line causes the "nigh" or left lead animal instinctively to throw its head to the right, to escape from the jerking, and the "jockey stick" guides the "off" animal to the right also, or "gee."

A little patience will teach the lead team to "gee" or "haw" if the guiding words "gee" or "haw" are shouted every time the line is used. By fastening the following teams to the double trees of the team ahead, they will soon learn to follow the team ahead without being tied, and, as a matter of fact, it is not as handy in turning around if each team is fastened, as it does not

---

**Engineering-Contracting*, Apr. 14, 1909.

permit them to cross over and out of the way of the chain while turning.

When a team has been properly trained in turning to the right or "gee," for example, the teams following the lead teams will step over on the left of the draft chain and follow it around until the chain is straight for the return trip; then each animal will cross over to his place on the right side of the chain.

In all of our team work we use but one driver, no matter how many teams are hitched to the load. In the hauling of gravel, sand or broken stone we use two or three wagons in a train. The trail wagons have a short trail tongue just long enough to permit the wheels to clear about three or four feet. The economy of this method of teaming is apparent when one driver is used to handle three wagons with three teams, for the wages of two teamsters are saved.

Cost of Plowing Farm Land With a Steam Traction Engine.*—It is only within the last ten years or so that the feasibility of plowing with traction engines has become generally recognized. The results obtained have been very satisfactory, and when it is remembered that one man with a plowing outfit can do much more work than six or eight with horses, the advantages of this method on the large farms of the West are obvious. Some data on the cost of steam plowing taken from letters written to the manufacturers by users of the traction engine are given below.

The first piece of work for which data are given was done in Missouri last year, a 20 hp. Rumley Standard traction engine and an 8-gang 14-in. Moline steam plow being used. An average of 18 acres per day was plowed, the cost of operating per day being as follows:

	Total.	Per acre.
Engineering	$ 3.00	$0.166
Water and fuel, hauled with team	2.50	0.139
Plowman	1.00	0.055
Coal	3.00	0.166
Plow sharpening, oil, etc.	0.50	0.027
Total	$10.00	$0.553

The next piece of work was done in North Dakota, a 30 hp. Rumley engine and Emerson 16-in. plow being used. The cost was as follows:

	Per acre.
Coal, at $6 per ton, 90 lbs. per acre	$0.27
Cylinder oil, at 40 cts. per gallon	0.01¼
Machine oil, at 20 cts. per gallon	0.01
Fireman, $2.50 per day	0.06¼
Water, team and man for hauling, $4 per day	0.10
Sharpening lays	0.01
Gear grease, 4 cts. per lb.	0.00½
Total	$0.47

It will be noted that there is no allowance made for engineer in the above, the owner of the outfit probably acting as such.

*_Engineering-Contracting_, June 16, 1909.

Charging this item up at $4.00 per day would bring the cost per acre to 57 cts. The fireman also probably acted as plowman. The outfit traveled 2¼ miles per hour, cutting 16½ ft. wide, thus averaging four acres per hour, allowing for stops.

The last piece of work was also done in North Dakota, a 30 hp. Rumley plowing engine being used. The ground was stony and hilly and a disc plow with 14 discs and cutting 11 ft. wide was used for breaking the ground. An average of 16 acres of ground was broken per 12-hour day, the cost being as follows:

	Total.	Per acre.
Coal, 2,300 lbs., at $7.50 per ton	$ 8.05	$0.50
Water, team and man for hauling	4.50	0.28
Engineer	3.00	0.11
Plowman (who also fired)	2.00	0.12
Oil and incidentals	1.00	0.06
Total	$18.55	$1.07

Later on this ground was put in shape for the drill at a cost of about 50 to 60 cts. per acre. To do this the traction engine was used to three sections of 21 discs cutting 18 ft. wide with a large drag and float behind.

None of the above costs include interest, repairs and depreciation.

Cost of Traction Engine Haulage of Ore.*—The hauling of crude ore from its mines in Lemhi County, Idaho, to Dubois, on the Oregon Short Line Ry., a distance of 85 miles, is being done with traction engine trains by the Gilmore Lead Mining Co., Ltd., and the following statement of the method and cost of operating these trains has been furnished by Mr. Robert N. Bell, State Inspector of Mines, Boise, Idaho. Formerly, it may be noted, the hauling was done by teams at a cost of from $10 to $12 per ton.

The train consists of four wagons or cars of steel and of 15 tons capacity each and a 110 hp. traction engine. The route is over a flat plain of fine gravelly soil and small sage brush, crossed by a number of creeks and irrigating ditches which are bridged. The road never gets very muddy and dries out rapidly as soon as the snow goes. There is one hill of about 10 per cent grade and three-quarters of a mile long approaching the mine; the engine handles one loaded or four empty cars on this hill. It also sets the cars one at a time at the loading bin on a 15 per cent grade. The coal used in making the trip amounts to about 4 tons per 24 hours, and is distributed in bins at intervals along the route. Water is available about every 15 miles, for which distance the tank capacity of the front car is sufficient.

The following costs of haulage are based on the records of the first trips made with the road practically in its virgin condition. A round trip took four days, working two 12-hour shifts per day and traveling 24 hours per day, with a total load of 40 tons.

**Engineering-Contracting,* May 29, 1907.

	Per shift.	Per trip.	Per ton.
1 engineer at $6	$ 6.00	$ 48.00	$1.20
1 fireman at $4	4.00	32.00	.80
1 swamper at $3.50	3.50	28.00	.70
Total labor	$13.50	$108.00	$2.70
Coal	3.00	12.00	0.30
Grand total	$16.50	$120.00	$3.00

Cost of Handling and Screening Cinders.—Cinders are often used in concrete and for other purposes. The following data are given by Mr. Ernest McCullough:

The cost of unloading and screening soft-coal locomotive cinders for a filter bed was as follows: The filter bed consisted of a lower layer of cinders 27 ins. thick and an upper layer 9 ins. thick. The lower layer comprised all cinders that would pass a screen of 1-in. mesh, but that would not pass a ⅝-in. mesh. The upper 9-in. layer would pass a ⅝-in. mesh, but not a ⅛-in. mesh. Unscreened cinders were shipped in gondola cars holding about 32 cu. yds. each, and were unloaded near the filter bed, screened and conveyed in wheelbarrows to place. The freight on car load was about $36. In one shipment of 16 cars there were 2 cars of ashes so fine as to be rejected without screening. The others gave the following proportions:

	Per cent.
Clinkers not passing 1-in. mesh	10
Cinders passing 1-in., but not passing ⅝-in. mesh	75
Cinders passing ⅝-in., but not passing ⅛-in. mesh	5
Fine dust, under ⅛-in	10
Total	100

It was found that cinders in a pile exposed for two weeks to the rain and weather were so disintegrated that 33% would pass a ⅛-in. mesh.

One man, using a coal scoop, would unload 32 cu. yds. from a car in 10 hrs., and as this yielded about 24 cu. yds. of coarse screened cinders, the cost of unloading was 6 cts. per cu. yd., wages being $1.50 a day. Another man, using a scoop, would shovel the cinders upon the first (1-in.) screen at the same rate. But it took two men, using ordinary square pointed shovels, to screen through the ⅝-in. screens, and these men screened the material twice, because it would not pass through these screens rapidly, nor at the first screening. A fair estimate of the cost of unloading and screening the coarse (1-in. to ⅝-in.) cinders is as follows, the cinders being measured in place in the filter bed:

	Per cu. yd.
Unloading cars	$0.06
Coarse (1-in.) screening	0.06
Fine (⅝-in.) screening twice	0.24
Wheeling and spreading in bed	0.08
Total	$0.44

The freight was about $1.50 per cu. yd. of screened cinders, and the cost of loading the cars about 16 cts. more, making a grand

total of $2.10 per cu. yd. of coarse screened cinders in place in filter beds.

Since all the cost of loading, unloading and freight has been charged to the coarse cinders, the cost of the fine cinders (⅝ to ⅛-in.) was merely the cost of screening them twice through a ⅛-in. screen, or 24 cts. per cu. yd. plus 8 cts. for wheeling and spreading. When these fine cinders were perfectly dry, once over the ⅛-in. screen was enough; but, if very wet and largely dust, screening three times over the ⅛-in. screen was necessary.

Since the proportion of fine screenings (⅛ to ⅝-in.) was so small, it was necessary to buy a number of car loads of screenings and waste all the material over ⅝-in. size. The freight, when charged against the fine screenings, was about $12 per cu. yd. due to the fact that not more than 3 cu. yds. of fine screenings could be obtained from a car load. An attempt was made to grind up some of the coarse screenings using a farmer's feed mill operated by horsepower. The mill would grind at the rate of 7½ cu. yds. of cinders in 10 hrs., but so many iron bolts and nuts were in the cinders that the mill was continually forced to stop, and finally had to be abandoned.

The specific gravity of soft coal cinders is 1.5, and the voids are frequently as high as 60%, in which case 1 cu. ft. of cinders weighs 37½ lbs.

Size, Weight and Price of Expanded Metal.—The following are standard sizes of expanded metal:

Mesh.	Gage of Metal.	Width of Metal.	Sectional area per ft. of width.	Lbs. per sq. ft.
3-in.	No. 10	5/32 in.	0.185 sq. in.	0.65
3-in.	No. 10	15/64 in.	0.278 sq. in.	0.94
3-in.	No. 10	5/16 in.	0.370 sq. in.	1.25
6-in.	No. 4	1/4 in.	0.259 sq. in.	0.86
6-in.	No. 4	3/8 in.	0.389 sq. in.	1.29

The 3-in. mesh is sold in 6 x 8-ft. sheets; the 6-in. mesh in 5 x 8-ft. sheets; and in both cases, 5 sheets per bundle. These are the common sizes, but expanded metal of the following meshes is also made; ½-in., ¾-in., 1½-in., and 2-in. The mesh is measured the short way across the diamond.

Expanded metal is sold by the square foot, but at prices equivalent to about 5 to 6 cts. per lb., depending upon the locality and the size of mesh. For expanded metal lath see index under "Lath, Metal."

Price of Mineral Wool.—Mineral wool is ordinarily made by pouring molten slag into water. It is largely used as a filling in hollow walls, because of its heat insulating property. I have also used it as a packing around water pipes that were exposed to the air. In carrying a pipe line across a bridge, for example, the pipe may be laid in a box and surrounded with mineral wool. A steam pipe may be jacketed in the same way.

Ordinary mineral wool weighs about 12 lbs. per cu. ft. and may be bought for about 1 ct. per lb.

Cost of Sodding.—Mr. Arthur Hay gives the cost of sodding a park in Illinois. The best sod shovel is a "moulder's shovel," with

a flat blade 10 ins. wide and 12 ins. long. The edge should be drawn down thin on an anvil and sharpened on a grindstone. The sod is cut through in parallel lines 14 ins. apart, with the shovel held at an angle so as to give bevel edges to the roll of sod. The sod strip is cut off square at the ends so as to make a strip about 8 ft. long (a square yard), and rolled up. One hundred of these rolls make a good wagon load, 80 being about the usual load. Sod should be cut as thin as possible, say 1½ to 2 ins. thick. Sod cut thicker, with the idea of saving all the roots, never unites with the bank when laid on an earth slope. When the rolls are laid, fine earth should be sifted into any cracks between the rolls. The sod should be thoroughly soaked with water after it is laid, and tamped to expel air underneath. A good tamper, or spatter, consists of a piece of 2-in. oak plank 10 ins. wide by 18 ins. long, strengthened by cleats across the ends and with a tough wood handle 2 ins. in diameter and 4 ft. long. One end of this handle is beveled off and bolted to the plank so that when the plank lies flat on the ground the end of the handle is waist high.

The following was the average cost of laying 20,000 sq. yds. of sod by day labor for the city of Springfield, Ill.:

	Cts. per sq. yd.
Cutting sod	1.6
Hauling sod	0.9
Laying sod	2.6
Watering sod	0.6
Spatting sod	0.1
Total	5.8

Men were paid $1.50 per 8-hr. day, and the sod cutters had a theory, very difficult to contend with, that 71 sq. yds. should constitute a day's work. Average contract prices in the vicinity were 10 cts. per sq. yd. of sod in place.

Seeding can be done for about $20 an acre, the cost of 80 lbs. of seed being $10, and the cost of labor being about $10 more. On slopes gentle enough to hold the seed without washing, seed is preferable to sod on account of its cheapness. An acre of sod, at 6 cts. per sq. yd., would cost about $300.

A Device for Cutting Soil for Sodding.*—Mr. A. N. Tolman gives the following:

Fig. 8 shows a sod cutter used at Sioux Falls, S. Dak. The construction is clearly shown by the illustration, but it may be well to add that the knife is curved (in plan) and pitches downward about ⅝ in. in its width of 2½ ins. It can be adjusted so that the sod can be cut in different thickness as required. I have not seen the cutter in use but two men and a boy with a team cut enough sod to load a slat wagon (1¼ cu. yds.) and rolled the sod and loaded the wagon in a trifle over an hour. This was so much faster than I had anticipated that I arrived on the scene only in time to find that the loaded wagon was more than the team could haul on

***Engineering-Contracting*, Aug. 11, 1909.

the muddy road. As the cutter is easily and cheaply made, and evidently a great improvement on the spade, it may be of interest to your readers.

Painting Data.—A gallon of iron oxide paint will cover 400 sq. ft. of wood surface, or 500 sq. ft. of iron surface, first coat. It requires about two-thirds as much paint for the second coat as for the first: and half as much paint for the third coat as for the first. Further data will be found on page 558.

A man, working 9 hrs. can paint (one coat) 2,000 sq. ft. of tin roof, or 1,000 sq. ft. of frame house, or 300 sq. ft. of bridge trusses. The shifting of scaffolds on house work accounts for the

Fig. 8.—Sod Cutter.

decreased time; and the smaller area of the surfaces of bridge trusses makes the work slower in bridge painting.

Consult the index under "Painting."

Cost of Painting a Tin Roof.—Mr. J. M. Braxton gives the following:

An old tin roof was showing rust spots, most of the paint being worn off. The tin was first rubbed with palmetto brushes and then swept clean. The area painted was 151,000 sq. ft., requiring 563 gals. of paint for two coats, or 267 sq. ft. per gallon for the two coats. The paint was:

396 gallons raw linseed oil.
35 lbs. dryer.
2,120 lbs. dry oxide of iron.

This mixture yielded 563 gals. of paint. Each man averaged 1,920 sq. ft., or 220 sq. yds. per day of 9 hrs. painted with one coat. It took 158 man-days to paint the roof, not including foreman's time.

Unloading Coal From Cars With a Clamshell.*—Broken stone, sand and gravel can be unloaded from cars very cheaply with a clamshell bucket, wherever the amount to be handled warrants the use of such a plant. The following data on unloading coal may also be applied to handling other materials.

At the Navy Yard at Washington, D. C., a locomotive crane, fitted with a 50-ft. boom and a 1½-cu. yd. Hayward clamshell bucket has been in use for unloading coal from cars. A description of the crane is as follows: Track gage, 4 ft. 8½ in.; wheel base, 8 ft.; greatest width, 9 ft. 10 in.; maximum working radius, 30 ft.; hoisting speed per minute, 250 ft.; rotating speed, three revolutions per minute; traveling speed, 350 ft. per minute; capacity, one trip per minute. The machine will lift 20,000 lbs. at a 12-ft. radius, and 7,500 lbs. at a 30-ft. radius. The engine is a 9 x 12-in., double cylinder, double drum engine, fitted with the necessary clutches and brakes for controlling the swinging and propelling movements of the machine. The crane was manufactured by the McMyler Mfg. Co., of Cleveland, O.

According to data furnished by Mr. F. E. Beatty, commandant of the Washington Navy Yard, the machine will unload approximately 400 tons of coal in eight hours. The crane used in loading coal cars from the coal bin will dip and load 48 tons in 20 minutes. In unloading a car, the bucket easily takes out three-fourths of the contents of the car. The remainder of the coal is taken into the boiler house by opening bottom run to bunkers with a chute, and thus requires no rehandling. In unloading the coal, one car is ahead of the crane, and the other behind, on the same track. The bucket takes a load, and, without stopping the swing of the boom, the coal is dropped; then the second car is reached, and the bucket filled. Commander Beatty considers that this makes not only less work for the man handling the levers, but also increases the output by 10 to 15 per cent.

A clamshell bucket is also used at the Polk street plant, Chicago, of the Western Electric Co., in handling coal from cars to storage bin. In this case, however, the bucket is operated by an electric overhead traveling crane. This machine was built by the Whiting Foundry & Equipment Co., of Harvey, Ill., for the Western Electric Co. It is of the three-motor type, and has a working load capacity of 10,000 lbs. The span, center and center of runway rails is 73 ft. 10 in. The lift (maximum vertical travel of hook) of the main hoist is 37 ft. The average travel is 50 ft. A 2-cu. yd. Hayward clamshell bucket is used.

Mr. G. A. Pennod, factory enginer for the General Electric Co., states that a 40-ton car can be unloaded in 1½ to 2 hrs., depending on the travel of the crane. From 5 to 6 cars a day, allowing for

*_Engineering-Contracting_, May 23, 1906.

switching, etc., can be unloaded in a day. It takes two men to unload a car; one man to operate the crane, and one man to shovel what coal remains in the corners of the car which the bucket, on account of its bulky nature, cannot pick up.

This last operation takes about as much time as unloading with the bucket alone, that is, the bulk of the coal in a 40-ton car can be unloaded in about 45 minutes, and it takes the same length of time for one man to shovel out what remains. The time of this last operation can, of course, be reduced by putting on more men.

If we assume that a man shovels coal at the rate of 4 tons per hour, it is evident that the clamshell bucket removes all the coal in a car except about 3 tons which must be shoveled out by hand.

It is apparent from the two foregoing examples that a contractor need not be afraid that a clamshell bucket will not clean up a carload of broken stone sufficiently well for practical purposes.

For data on handling stone with clamshells, consult the index under "Clamshell."

Cost of a 28-Mile Telegraph Line.*—The data to be given relate to a telegraph line 28 miles long, built in British Columbia. There were 32 poles to the mile, strung with a single No. 8 B. B. galvanized iron wire. The cost of the poles was very much less than it would be in most localities, but, since quotations on poles are readily secured, proper substitutions can be made in the following tabulated values for any particular case.

Regarding telegraph wire, a word of explanation may be helpful. Until recently the size of wire commonly used for lines of medium length, up to 400 miles, was No. 9, weighing 305 lbs. per mile, but No. 8 is now used more frequently. There are two grades commonly used: The E. B. B., or "extra best best," and the B. B., or "best best." A third grade, S, or "steel," is also used for short circuits. The following are the weights of galvanized wire:

	Lbs. Per mile.	Lbs. Per ft.	Ft. Per lb.
No. 6	570	0.108	9.2
No. 7	450	0.085	11.7
No. 8	380	0.072	14.0
No. 9	305	0.058	17.4
No. 10	250	0.047	21.2

The itemized cost of this 28-mile line was as follows:

Labor:	Per mile.
1.0 day, foreman at $3.50	$ 3.50
1.0 day, sub-foreman at $3.00	3.00
2.7 days, climber at $2.50	6.75
2.5 days, framer at $2.25	5.62
0.7 day, blacksmith at $2.25	1.58
4.6 days, groundman at $2.00	9.20
12.5 days total at $2.40	$29.65

*Engineering-Contracting, July 10, 1907.

Materials:

32 poles (25-ft.) at $1.25	$40.00
32 wooden brackets at 1¼ cts.	0.40
32 glass insulators at 0.4 cts.	1.28
5 lbs. nails at 2½ cts.	0.12
½ lb. staples at 0.3 cts.	0.02
380 lbs. No. 8 BB galv. wire at 5 cts.	19.00
2 lbs. tie wire at 3 cts.	0.06
Total materials	$60.88
Total labor and materials	90.53

The labor includes the cost of digging holes, erecting poles, stringing the wire, etc. The poles were distributed by train, and the price of $1.25 per pole does not include the train service.

A pole 12 ins. diameter at the butt and 7 ins. at the top, contains ½ cu. ft. of wood per lin. ft. Hence there are about 12½ cu. ft. of timber in a 25-ft. pole. Knowing the kind of timber, it is easy to estimate the weight of poles, and consequently the freight for any given haul. If the timber weighs 40 lbs. per cu. ft. the weight of a pole is about 500 lbs. With 32 poles per mile, the weight is 8 tons for the poles. See page 952 for weights of poles.

Cost of a Telephone Line.—In *Engineering-Contracting,* May 27, 1908, an article by Mr. L. E. Hurtz gives in detail the methods of building an all-cable telephone plant in a suburb of a city, the population of the suburb being 3,000. The following is the summary of unit costs:

	Cost each.
Poles, unloaded, 363	$0.07
Poles shaved (average, 30 ft. long)	0.22
Poles roofed (and a very few gains cut)	0.07½
Poles hauled (average, 30 ft. long)	0.25
Poles set (average, 30 ft. long)	0.33
Poles set (average, 40 ft. long)	0.69
Poles bored for steps	0.18
Poles stepped	0.20
Pole holes dug, average, 30 ft., pole holes 5½ ft. deep	0.47½
Anchors, holes dug, 99	0.45
Anchors set, 99	0.58
X-arms fitted	0.07
X-arms distributed	0.09
X-arms put on	0.15½
Guys put on	1.00
Stringing and pulling messenger, per ft.	0.00¼
Cable pulled, average 25 pr., per ft.	0.00¾
Cable clipped (hangers put on), per hanger	0.00½
Staking out line, per pole	0.10
Poles pulled and holes filled, per pole	0.65
Cable unloaded, average, 25 pr. per ft.	0.00 1/5
Drops strung, per drop	1.04
Bare wire strung, per single wire per mile	2.75

Average total cost of labor and material for splicing lead covered, paper insulated telephone cable:

25 pr. cable	$ 2.86
50 pr. cable	2.95
75 pr. cable	4.40
100 pr. cable	5.75
150 pr. cable	6.22
200 pr. cable	8.37
250 pr. cable	10.00
300 pr. cable	10.00

Cost of Two Telephone Lines.*—Two short lines were built, one 10 miles long and the other 14 miles long. The cost of the 10-mile line was as follows per mile:

Labor:	Per mile.
1.7 days foreman at $4.00	$ 6.80
1.7 days sub-foreman at $3.00	5.10
4.0 days climbers at $2.50	10.00
10.5 days groundmen at $2.25	23.63
17.9 days total at $3.10	$ 55.53
Materials:	
28 poles at $1.50	$ 42.00
28 cross arms at $0.15	4.20
28 steel pins at $0.04	1.12
28 glass insulators at $0.04	1.12
56 lag screws and washers at $0.015	0.84
305 lbs. No. 9 galv. wire at $0.042	12.81
Total materials	$ 62.09
Total labor and materials	117.62

More than 90% of the poles were 25 ft. long. The rest were 30 to 40 ft. in length.

The cost of the 14-mile line was as follows per mile:

Labor:	Per mile.
2.2 days foreman at $3.50	$ 7.70
2.2 days sub-foreman at $3.00	6.60
5.3 days climber at $2.75	14.58
11.4 days groundman at $2.25	25.64
21.5 days total at $2.54	$ 54.52
Materials:	
32 poles at $1.50	$ 48.00
32 brackets at $0.015	0.48
380 lbs. No. 8 galv. wire, $0.042	15.96
10 lbs. No. 9 galv. wire, $0.042	0.42
1¼ lbs. fence staples, $0.025	0.04
32 insulators, $0.04	1.28
Total materials	$ 66.18
Total labor and materials	120.70
2 telephones at $12.50	25.00
200 ft. office wire	1.40

Considering the low cost of telephone lines of this character, it is surprising that they are not more frequently built for use on construction work. For temporary purposes, a much cheaper kind of poles could be used. For example, a very substantial pole could be made by nailing together two 1 x 4-in. boards, so as to form a post having a T-shape cross-section. Such a pole would contain only two-

**Engineering-Contracting,* July 24, 1907.

thirds of a foot, board measure (⅔ ft. B. M.) per lineal foot of pole. At $24 per M for the boards, a pole 20 ft. long would cost 32 cts.

Hence the poles would cost less than $10 per mile of line. The No. 9 wire would ordinarily cost less than $13 per mile, and $3 more would cover the cost of the remaining line materials, making a total cost of $26 per mile for materials. We have no data as to the labor of erecting such a line, but it would certainly be less than $15 per mile; and in soil where post hole diggers could be used the cost would be considerably less. In fact, a telephone line built for $35 a mile might easily be obtained under fairly favorable conditions. Moreover it could be taken down and used many times on subsequent construction. Such a light pole line, however, would not stand up in severe winter weather.

Life of Telephone Line Equipment.*—Some time ago the city of Chicago appointed a special commission, consisting of Prof. Dugald C. Jackson, Dr. George W. Wilder and William H. Crumb, to investigate matters pertaining to the telephone situation in that city. In connection with its report the commission gave the following data as to the life and depreciation of telephone equipment:

Property:	Life in years	Per cent to depreciation account	Per cent salvage.	Per cent to reconstruction and insurance
Underground conduit, main, clay in concrete	50	.89	0	1½
Underground conduit, main, fibre, etc.	20	3.72	0	1½
Underground conduit, subsidiary	20	3.72	0	2
Underground cable, main	20	3.72	..	2
Underground cable, subsidiary	15	5.38	40	2
Aerial cable	15	5.38	..	3
Poles, including crossarms, etc.	10	8.73	0	4½
Aerial strand	12	7.05	0	3½
Aerial cable, terminals	12	7.05	0	3
Aerial wire, copper	15	5.38	70	3
Drop wires, copper	8	11.25	15	4
Subscribers' station instruments	10	8.73	5	2
Private branch exchange switchboards	8	11.25	20	2
Central office switchboards	8	11.25	20	2
Buildings, fireproof	40	1.33	0	1
Teams, tools, furniture, etc.	4	23.92	10	0

Vitrified Conduit Data.—Vitrified conduits for carrying electric wires underground are made in single or multiple ducts. A single duct is a pipe 18 ins. long with a round or square bore ranging from 3¼ to 4 ins. diameter. Multiple ducts are made with two or more ducts in one piece. The common multiples are 2, 3, 4, 6 or 9 ducts in one piece. The lengths of the pieces are 24 or 36 ins. Ducts are sold by the duct-foot, and the present price in New York City

*_Engineering-Contracting_, Feb. 12, 1908.

7

is about 3½ cts. per duct-foot. A 6-duct multiple has 6 duct-f per lin. ft., and its price is therefore 6 × 3½, or 21 cts. per lin. ft the 6-duct piece. The weight varies somewhat with different ma facturers, but 8 lbs. per duct foot may be used for estimating frei and haulage.

I am informed by one of the large manufacturers that the 9-du multiple is not so popular as it once was, due to loss by breakage.

The outside dimensions of vitrified conduits are about as follows:

Number of ducts in the piece...	1	2	3	4	6	9
Dimensions of the piece, ins....	5x5	5x9	5x13	9x9	9x13	13x1

These ducts are all square bore, 3¼ ins., square with rounde corners.

Cost of Laying Electric Conduits.—My own cost records for thi class of work cover only two sizes of vitrified pipe conduits encased in concrete. One of these conduits was made of 4-duct pipe, each duct being 3½ ins. inside diameter, the 4 ducts being baked together in one piece 18 ins. long. First a trench was dug 2 ft. 8 ins. deep and 18 ins. wide, then a bed of concrete 4 ins. thick was laid in the trench. Upon this concrete the conduit was laid, every joint being wrapped with a strip of cheap cotton cloth. Then concrete was packed on both sides of the conduit and 4 ins. thick over its top. The labor cost of laying this conduit, not including the cost of trenching and the cost of making and placing the concrete, was as follows: Two men laying the duct pipe and one helper delivering pipe from piles along the sidewalk, averaged 60 lin. ft. of 4-duct conduit laid per hour, which is equivalent to 120 ft. of single duct per hour. With wages of duct layers at 20 cts. each per hour, and helper at 15 cts. per hour the cost of laying was a trifle less than 1 ct. per lin. ft. of 4-duct conduit, or ¼ ct. per ft. of single duct.

In laying a 9-duct conduit (each piece of pipe having 9 ducts instead of 4 as above), two men laying were supplied with pipe by two helpers. This gang averaged 30 lin. ft. of 9-duct conduit per hour, at a cost of 2.3 cts. per lin. ft. of conduit, or ¼ ct. per ft. of single duct. From this it appears that the labor cost of laying the pipe is practically the same per duct-foot, whether 4-duct or 9-duct conduit is laid.

At another time, one man laying a single duct line (exclusive of trenching and concreting) averaged 66 lin. ft. per hour, at a cost of a trifle less than ¼ ct. per ft. The work in all these cases was done by day labor for the company.

Cost of Vitrified Conduits, Memphis, Tenn.—Mr. F. G. Proutt gives the following data on electric vitrified conduit construction at Memphis, Tenn., in 1903: The work was done by day labor, the wages of common laborers (negroes) being $1.50 per day. There were about 3,700 ft. of trenches containing 27 ducts, and 7,200 ft. of trench containing 18 ducts, besides which there were 575 ft. of

trench containing from 6 to 60 ducts, making in all 11,475 ft. of trench and 252,000 duct feet. An 18-duct conduit was made up of three 6-duct sections (no single duct sections were used), each section measuring 9 x 13 ins., sections being laid one on top of the other. The ducts were surrounded on all sides with concrete 3 ins. thick, making 6 ins. of concrete, 27 ins. of ducts and 30 ins. of backfill, or a trench 5¼ ft. deep for an 18-duct conduit. The width of the duct, 13 ins., plus 6 ins. for concrete, gives a trench 19 ins. wide, or about 8¼ cu. ft. (less than ⅓ cu. yd.) of excavation per foot of trench. The 27-duct conduit was made up of 4 multiple ducts of 6 ducts each, and one multiple of 3 ducts, laid in tiers, making the trench 6¼ ft. deep and 19 ins. wide, or about 9.4 cu. ft. per foot of trench. Roughly speaking, all the trench work averaged ⅓ cu. yd. excavation per foot of trench. All 6-duct sections were 3 ft. long, and all 3-duct sections were 2 ft. long.

The executive force consisted of 1 general foreman at $3; 1 foreman of pipe layers; 1 foreman of concrete mixing gang; 1 foreman in charge of digging for manholes; 1 foreman in charge of back-filling and hauling away, and 1 timekeeper. There were 8 men on manholes and service boxes, 80 men trenching, concreting and pipe laying. The best day's work was 703 ft. of trench and 15,156 duct-feet.

In laying the ducts, the 3-in. concrete bottom was first placed, then 2 men in the trench laid the lower tier or run, 2 men on the bank handling the sections down by means of a rope run through one of the holes. This run was followed by a similar gang of 4 men working a few lengths back. Three dowel pins were used in each section. The joint was made with a strip of cheap canvas 5 ins. wide by 5 ft. long laid on the bottom before placing the ducts. A boy followed along, wrapping the canvas over the top joint and painting the lap with asphaltum. To cut the canvas into strips a table was made with a saw kerf in it 5 ins. from one edge and at this edge was a strip against which to push the bolt of cloth. A large butcher knife was then run through the saw kerf and cloth, cutting off a strip 5 ins. wide and the length of the bolt. This strip was wound on a reel whose circumference was 5 ft., and a cut through the cloth at the circumference made strips 5 ft. long.

The concrete was mixed with "Dromedary" mixers costing about $200 each. A "Dromedary" mixer holds about ⅝ cu. yd. of concrete, and is hauled by two horses in tandem. Half the charge of sand is shoveled in, then the cement, then the rest of the sand, and finally the stone. The door is closed and the mixer hauled about 150 ft. to the water tank and from 6 to 8 pails of water are thrown in. If the concrete must be rehandled the mixer is hauled to a dumping board 6 ft. wide by 24 ft. long, made in two 6 x 12-ft. sections.

The cost of 252,000 duct-feet, laid in 11,475 ft. of trench, was as follows:

254,500 duct feet (1% broken), at 5½ cts.	$13,997
45 cars of ducts unloaded, at $7.50	338
Labor trenching, backfilling, concreting and duct laying	7,745
Materials for 882 cu. yds. of 1:4:8 concrete,* at $5.22	4,604
32 brick manholes,† at $115	3,680
31 manhole drains,‡ at $86	2,666
48 service boxes,§ at $30	1,520
4,300 lin. yds. canvas (5 ft. wide), at 5 cts.	215
5 bbls. asphalt paint, at $30	150
40,000 dowel pins for ducts, at ½ ct.	200
Tools	800
City water	50
Plumbers repairing water pipes	100
New sidewalks	600
Repaving city streets	1,000
City inspection	195
Engineering	1,000
Incidentals	1,140
252,000 duct feet, at nearly 16 cts.	$40,000

*Each cubic yard of 1:4:8 concrete required 0.96 bbl. (a bbl. being counted as 4 cu. ft.) cement at $2.10 per bbl.; 0.56 cu. yd. of sand at $1.25 per cu. yd.; and 1.36 short tons of broken limestone at $2 a ton.

†Each manhole was 8-sided, 5 ft. wide by 7 ft. long and 6½ ft. deep, inside measure, with 13-in. brick walls, a 6-in. concrete floor, and a 12-in. concrete top reinforced by old rails. There were 3,200 bricks in each manhole at $7.50 per M; there were nearly 4 cu. yds. of concrete in the bottom and top at $5.75 per cu. yd. for materials. Masons were paid $6 a day and helpers $2. The cost of excavating for and building a manhole averaged about $40. The iron rails cost $5. The cast-iron cover for each manhole weighed 1,150 lbs. costing 1.9 cts. per lb.

‡Manhole drains averaged 170 ft. long of 6-in. sewer pipe, costing $10 for materials and $76 for labor.

§Service boxes contained 325 bricks each, and were 3 ft. square inside, with 9-in. walls, and provided with cast-iron covers like the manhole cover.

The designs of manholes, methods of construction and other details as to this work are given in Mayer's "Telephone Construction—Methods and Cost," p. 243 et seq.

Cost of Brick Manholes for Electric Conduits.—Square manholes were built with brick walls 12 ins. thick. The bottom of the manhole was concrete, and the top was reinforced concrete. The following data relate only to the brick work: Each manhole contained 4.6 cu. yds. of brick masonry, and the following gang averaged 1¾ days to each manhole, the day being 8 hrs. long:

2 masons, at $3.00	$ 6.00
3 helpers, at $1.50	4.50
Total per day	$10.50

Therefore, it cost $18.35 per manhole for the labor on the brick work, which is equivalent to $4 per cu. yd. of brick masonry. Since each manhole contained 2,140 bricks, each mason averaged about 600 bricks laid per 8-hr. day. This was very slow work. It was done by day labor for a company. See Mayer's "Telephone Construction—

Methods and Cost" for the design, methods of construction and itemized costs of several hundred brick and concrete vaults.

Methods and Cost of Laying Vitrified Conduits for Electric Wires.*—Considering the large amount of vitrified conduit work that is being done, there is surprisingly little in print on the cost of laying conduits for electric wires. In our issue of July 11 we gave the costs of excavation and of concrete work on the Atlantic Ave. subway work of the Long Island R. R. The concrete retaining walls of that subway contained many thousand feet of vitrified ducts, and we give herewith some data bearing upon the cost of hauling and laying the ducts for the electric wires. The ducts were of standard 3-ft. length, having an inside diameter of 3¼ ins. Multiple duct conduits were laid, being for the most part, 4-hole pieces.

The conduits were unloaded from boats, hauled about 1½ miles, and piled up ready for use. The cost of unloading, hauling and piling was 0.8 ct. per duct-foot; and, as a duct-foot weighs about 8 lbs., this is equivalent to $1.30 per ton. Laborers received 15 cts. an hour, team and driver 45 cts.

The cost of laying conduits during the year of 1903 was as follows:

	Duct-ft. laid.	Labor, days.	Pay roll.	Cost per duct ft.
January	1,942	10	$ 15	0.8 ct.
February	1,636	9	13	0.8 ct.
April	4,512	32	55	1.2 ct.
May	30,653	154	254	0.8 ct.
June	37,715	205	357	0.9 ct.
July	27,893	179	288	1.0 ct.
August	15,293	92	142	0.9 ct.
September	14,170	63	108	0.8 ct.
October	10,037	43	74	0.7 ct.
Total	143,851	787	$1,316	0.9 ct.

From this it appears that the cost of laying was a trifle less than 1 ct. per duct-foot, and that the average wages were $1.66 per day of 10 hrs. This is the average of the common laborers delivering ducts and the skilled men laying ducts.

It required 150 bbls. of Portland cement to lay the 143,851 duct-feet, or 1 bbl. per 960 duct-feet.

During the year of 1904, there were 227,600 duct-feet laid, requiring 240 bbls. of cement and 975 days labor. The average wages paid were $1.71 per day, and the average cost was 0.8 ct. per duct-foot for laying. During the best month, 30,700 duct-feet were laid at a cost of 0.6 ct. per duct-foot for laying, which indicates that the workmen were not very efficient during the previous months.

In our February issue we gave the itemized cost of building a section of the New York Subway, and from that article we have ab-

Engineering-Contracting, July 25, 1906.

stracted such data as pertain to conduit construction, for the purposes of comparison, as follows:

	Per duct-ft.
Labor	1 ct.
Materials	5 cts.
Total	6 cts.

The cost of materials for 123,483 duct-feet in the New York Subway were as follows:

123,483 duct-ft., at 4½ cts.	$5,556
6,000 sq. yds. burlap, at 4½ cts.	270
275 bbls. Portland cement, at $1.58	435
68 cu. yds. sand, at $0.50	34
13 sets mandrels, at $2	26
Total, 123,483 duct-ft., at 5 cts.	$6,321

One barrel cement was used for every 440 duct-feet.

As an average of a large amount of work on the New York Subway, the following data were deduced: 100 duct-feet require 0.22 bbl. cement, 0.055 cu. yd. sand and 4.86 sq. yds. burlap. The conduits used were 4-hole pieces in 2-ft. lengths, 9 ins. square, built up in advance of the concrete side walls which surrounded them.

On another section of the New York Subway where more than 500,000 duct-feet were laid, the cost of the labor of laying was 1½ cts. per duct-foot. And on still another section, where 60,000 duct-feet were laid, the cost was as high as 2¼ cts. per duct-foot for labor of laying. This last appears to indicate an immense amount of loafing; although the New York Subway work at best was poorly managed by the contractors.

However, the wages paid on the New York Subway work were high, being $5.20 per 8-hr. day for the bricklayers who laid the ducts. We are informed that the men who handed the ducts to the layers were classed as "mason's helpers," in which case they would have received about $3 a day, being union men. But in the itemized list of workers and wages of men on the New York Subway, given in our February issue, we find no "mason's helpers." This makes it doubtful whether the helpers were credited as receiving more than the wages of common laborers, or $1.50 a day.

In laying the ducts, there were sometimes 2 helpers to 1 bricklayer, sometimes 2 helpers to 2 bricklayers. It was the duty of one of the helpers to prepare the muslin sheets that were wrapped around the joints of the ducts. The sheets were cut into strips 8 ins. wide and 3½ ft. long; then they were laid on boards and soaked with neat cement grout, using a whitewash brush for the purpose. This helper sometimes passed the cemented cloths to the layer; but sometimes a helper passed the cemented cloths and the ducts to the layer.

The conduits were laid 16 ducts high, usually back of the steel side columns and against the waterproofed 4-in. backing wall of brick on each side of the subway. The ducts were laid to break joint, with a cemented cloth around each joint, then a little mortar was slushed in to smooth up the line of ducts. Mandrels were used in laying, the mandrel being 4 ft. long, and extending through two ducts.

The specifications for this Long Island R. R. work are given in Mayer's "Telephone Construction—Methods and Cost," p. 278 et seq.

Cost of Pole Lines, Vitrified Conduits, Manholes, Etc.—References. —A complete treatise on the methods and cost of telephone line construction, with data equally applicable to electric power transmission lines, is Mayer's "Telephone Construction—Methods and Cost." The cost data were secured from work aggregating 50 miles of underground conduit, and the pole line costs cover an even more extensive mileage. The same book contains other similar data gathered by Mr. J. C. Slippy.

Labor Cost of an Electric Transmission Line.—In *Engineering-Contracting*, Feb. 5, 1908, two pages are devoted to the methods and cost of constructing a 20-mile electric power transmission line. A full abstract of the same is given in Mayer's "Telephone Construction—Methods and Cost," p. 227 et seq. The following is merely a brief summary of the labor cost per mile of line:

	Per mile.
Hauling poles	$ 18.75
Digging (46 poles) holes	45.47
Raising poles	35.47
Dapping crossarms	14.14
Hauling and placing crossarms and insulators	21.01
Labor on guy poles	18.28
Trimming trees and bushes	20.94
Stringing and fastening wires	74.06
Changing old poles	35.31
Total	$283.43

Laborers received $1.50; linemen, $2.50; teams, $4.50. The poles were 32 ft. long, set 5 ft. deep. There were two crossarms to a pole, each holding 8 pins; but a third dap was made in each pole to provide for a future crossarm. Twelve wires were strung.

Cost of Transmission Line for Interurban Electric Railways.*— The following is a rather brief abstract of an article by Mr. E. P. Roberts and Mr. J. C. Gillette:

The following data on overhead line construction for interurban electric railways are based on actual practice and on the average costs of a large number of lines in different sections of the United States. The elements of interurban electric railway overhead line construction are: (1) A conductor from which the cars take electrical energy, and (2) the supporting of this conductor, which may be directly by brackets or by cross spans, which in turn are supported by poles. These two methods of construction are termed respectively bracket suspension and cross-suspension. The trolley wire may be supported either directly from insulators carried by the brackets or spans, or by steel cable, which in turn is supported by the brackets or spans. The former is the old and standard method of trolley construction so long used on direct current lines, while the latter is the new "catenary" type of construction. The work for a 600-volt direct current line will be considered first and then the work for a line for higher voltage alternating or direct current motors.

**Engineering-Contracting*, Dec. 11, 1907.

The costs submitted are probable costs between limits, but even though a maximum limit is given, the actual cost may sometimes exceed these figures, depending on local conditions.

Starting from the standpoint of the cheapest practicable construction, we have 30-ft. poles, 90 to 100 ft. spacing, and bracket supports, and with double overhead No. 000 trolley. The cost of such construction will aproximate the figures given by Table IV.

TABLE IV.—COST PER MILE OF BRACKET CONSTRUCTION SINGLE TRACK 600 V. TWO NO. 000 TROLLEY WIRES, POLES SPACED 100 FT.

Fifty-three 30-ft. poles in place and framed, poles delivered on cars $4.00 to $6.00	$ 325.00	$ 475.00
Fifty-three brackets in place with fittings	180.00	210.00
Ears, hangers, etc., in place	50.00	75.00
Two miles No. 000 trolley with splicers, at 20c-26c	1,100.00	1,400.00
Erecting same	100.00	150.00
Siding construction pro rated	75.00	100.00
Curve construction 1,500 ft. additional cost	50.00	75.00
Five anchors	8.50	15.00
Two hundred ft. strand for guys	2.25	2.50
Two half anchorages	5.00	10.00
Lags, clamps, etc	5.00	8.00
Per cent on material for handling	75.00	100.00
	$1,975.75	$2,620.50
Add for lightning arrester	10.00	20.00
Add for telephone system pro rated	75.00	100.00
	$2,060.75	$2,740.50
If all poles are anchored add	160.00	265.00
If 35-ft. poles are used add (poles $6.00 to $8.50)	130.00	160.00
Total	$2,350.75	$3,165.50

If for any reason, it is decided to use cross suspension instead of bracket construction with the same pole spacing and size of trolley, then the approximate cost will be as given by Table V.

TABLE V.—COST PER MILE OF SPAN CONSTRUCTION SINGLE TRACK 600 VOLT TWO NO. 000 TROLLEY WIRES, POLES SPACED 100 FT.

One hundred and six 30-ft. poles in place and framed, poles delivered on cars $4.00-$6.00	$ 650.00	$ 950.00
Ears, hangers, etc., in place	50.00	75.00
Span wire erected	60.00	85.00
Two miles No. 000 trolley at 20c-26c	1,100.00	1,400.00
Erecting same	100.00	150.00
Siding construction, pro rated	75.00	100.00
Curve construction, additional cost	35.00	60.00
Five anchors	8.50	15.00
Two hundred ft. strand for anchor guys	2.25	2.50
Two half anchorages	5.00	10.00
Lags, clamps, etc	5.00	8.00
Per cent on material for handling	100.00	150.00
	$2,190.75	$3,005.50
Lightning arresters	10.00	20.00
Telephone system, pro rated	75.00	100.00
If all 35-ft. poles are used (poles at $6.00 to $8.50)	260.00	320.00
If poles are anchored add	320.00	530.00
Total	$2,856.75	$3,975.50

In case transmission wires are required for transmission of electric energy from the power house to substations, such transmission wires may be placed entirely on crossarms, or in the case of three-phase transmission, two of such wires may be on one two-pin arm and the third wire on a pin on the top of the pole or on a bracket on the side of the pole. Of course the pole top cannot be used if a ground wire is located at such point. The cost of construction on a three-phase transmission line will approximate the figures given by Table VI.

TABLE VI.—COST PER MILE OF BRACKET CONSTRUCTION SINGLE TRACK 600 VOLT TWO NO. 000 TROLLEY WIRES, POLES SPACED 100 FT. WITH THREE PHASE 33,000 VOLT TRANSMISSION LINE ON TROLLEY LINE POLES, 2-PIN CROSSARM AND POLE TOP PIN CONSTRUCTION.

Fifty-three 35-ft. poles in place and framed, poles delivered on cars at $6.00 to $8.50	$ 455.00	$ 635.00
Ears, hangers, etc., in place	50.00	75.00
Fifty-three brackets in place with fittings	180.00	210.00
Two miles No. 000 trolley with splicer at 20c-26c	1,100.00	1,400.00
Erecting same	100.00	150.00
Siding construction, pro rated	75.00	100.00
Curve construction 1,500 ft. additional cost	65.00	100.00
Five anchors	8.50	15.00
Two hundred ft. strand for guys	2.25	2.50
Two half anchorages	5.00	10.00
Lags, clamps, etc.	5.00	8.00
Fifty-three 4 x 5 in. x 4 ft. 6 in. crossarms	16.00	22.00
One hundred and fifty-nine 2 x 13-in. oak pins paraffined	9.00	11.00
One hundred and fifty-nine 33,000 volt porcelain insulators	90.00	120.00
One hundred and six 20 x 1¼ x ¼ in. crossarm braces galv.	5.00	6.50
One hundred and six ⅜ x 5 cge. bolts	1.00	1.25
Fifty-three ½ x 4 lag bolts	.60	.75
Fifty-three ⅝ x 13 mch. bolts	3.00	3.75
Erecting arms, pins and insulators	25.00	35.00
Three miles No. 2 copper wire with splicers at 20c-26c	638.40	829.92
Erecting same	125.00	170.00
Per cent on material for handling	140.00	190.00
Total	$3,098.75	$4,095.67
Add for trolley lightning protection	10.00	20.00
Add for transmission lightning protection	50.00	250.00
Add for telephone system pro rated	75.00	100.00
Total	$3,233.75	$4,465.67
If all poles are anchored add	160.00	265.00
Total	$3,393.75	$4,730.67

From the above the principal unit costs of the cheapest practicable character of line work can be ascertained, and such additions must be made as are necessary for special overhead work around car shops, and in connection with bridges, city work or other special conditions; also the cost of copper for feeders or for transmission must be added in accordance with the plan decided upon.

Tables VII to IX show the average cost between limits of different types of catenary construction.

TABLE VII.—COST PER MILE SINGLE TRACK 9-POINT CATENARY 150-FT. POLE SPACING, 6,600 VOLT.

36 35-ft. poles in place and framed, poles taken at $6.00 to $8.00 delivered	$ 310.00	$ 430.00
36 brackets with fittings, in place	120.00	150.00
5,280 ft. No. 0000 trolley, 3,382 lbs., at 20c to 26c per lb.	676.00	879.00
5,300 ft. ⅝-in. high strength steel messenger cable	110.00	130.00
36 messenger insulators	15.00	30.00
36 spans catenary hangers	40.00	72.00
5 anchors	8.50	15.00
200 ft. ⅜-in. high strength strand for guys	2.25	2.50
10 steady braces for curves	30.00	40.00
10 strain insulators	11.00	15.00
Per cent on material for handling, etc.	100.00	130.00
Labor erecting curve trolley 1,500 ft. additional	50.00	75.00
Labor erecting catenary trolley	160.00	200.00
2 half anchorages	20.00	30.00
Siding construction, pro rated	100.00	150.00
Lags, clamps, etc.	10.00	15.00
	$1,762.75	$2,363.50
Add for lightning arresters	10.00	60.00
Add for galv. wire lightning protection	150.00	200.00
Add for telephone system, pro rated	100.00	150.00
	$2,022.75	$2,773.50
If all poles are anchored add	108.00	180.00
If brackets are insulated	40.00	60.00
Total	$2,170.75	$3,013.50

TABLE VIII. COST PER MILE OF DOUBLE TRACK 9-POINT CATENARY, CENTER POLE, 150-FT. POLE SPACING, 6,600 VOLT.

36 35-ft. poles in place and framed, poles delivered [illegible]s $6.00 to $8.00 each	$ 310.00	$ 430.00
72 brackets with fittings in place	240.00	300.00
10,500 ft. trolley, 6,764 lbs., at 20c to 26c per lb.	1,352.00	1,758.00
10,600 ft. ⅝-in. high strength steel messenger cable	220.00	260.00
72 messenger insulators	30.00	60.00
72 spans catenary hangers	80.00	144.00
10 anchors	17.00	30.00
300 ft. ⅜-in. strand for guy	3.50	4.00
20 steady braces for curves	60.00	80.00
20 strain insulators	22.00	30.00
10 30-ft. pull-off poles in place and framed	100.00	130.00
Per cent for handling material, etc.	110.00	140.00
Labor erecting catenary trolley	320.00	400.00
Labor erecting curve trolley, 3,000 ft. add	100.00	150.00
2 half anchorages	40.00	60.00
Siding construction, pro rated	200.00	300.00
Lags, clamps, etc.	10.00	15.00
	$3,214.50	$4,291.00
Add for lightning arresters	10.00	120.00
Add for galv. wire lightning protection	150.00	400.00
Add for telephone line	100.00	150.00
Total	$3,374.50	$4,961.00

TABLE IX.—COST PER MILE OF DOUBLE TRACK 9-POINT CATENARY, DOUBLE POLE LINE, 150-FT. SPACING, 6,600 VOLT.

72 35-ft. poles in place and framed, poles at $6.00 to $8.50 each delivered on cars......	$ 620.00	$ 860.00
72 brackets with fittings in place............	240.00	300.00
10,560 ft. No. 0000 trolley, 6,764 lbs., at 20c to 26c per lb............................	1,352.00	1,758.00
10,600 ft. ⅝-in. high strength steel messenger cable	220.00	260.00
72 messenger insulators......................	30.00	60.00
72 spans cat. hangers........................	80.00	144.00
10 anchors	17.00	30.00
300 ft. ⅝-in. strand for guy..................	3.50	4.00
20 steady braces for curves..................	60.00	80.00
20 strain insulators.........................	22.00	30.00
Per cent for handling material..............	130.00	160.00
Labor erecting 2 miles catenary construction..	320.00	400.00
Labor erecting 3,000 ft. curve construction add	100.00	150.00
2 double track half anchorages..............	40.00	60.00
Siding construction pro rated...............	200.00	300.00
Lags, clamps, etc............................	10.00	20.00
	$3,444.50	$4,616.00
Add for lightning protection.................	20.00	240.00
Add for galv. wire lightning protection......	150.00	400.00
Add for telephone line.......................	100.00	150.00
	$3,714.50	$5,406.00
If all poles are anchored....................	216.00	360.00
If all brackets are insulated................	80.00	120.00
Total	$4,010.50	$5,886.00

In deciding whether the pole line for double track shall be a double pole line or a center pole line, the character of the grading on the right-of-way will have to be taken into consideration. If, as in the Middle West, the country is practically level and no expensive cuts or fills are required, possibly the single pole construction will show a saving over the double pole; however, where there are expensive fills and cuts, the double pole construction will show a saving over the single pole, not in itself, but in the fact that the roadbed will not have to be as wide as for the single pole construction.

Estimating the Horse Power of Contractors' Engines and Boilers.*—The size of an engine is usually expressed in terms of the diameter of the cylinder bore by the length of the piston stroke. In a 6 x 8 engine, the cylinder has a bore of 6 ins. and the piston has a stroke of 8 ins. This stroke is, of course, just twice the length of the "throw" of the crank arm. Bear in mind, therefore, that the "size of cylinder" as given in catalogues is the bore of the cylinder by the *stroke* of the piston, and not by the full length of the cylinder.

If a contractor's engine is designed to have a piston speed of 300 ft. per minute, and is using steam with a boiler pressure of 100 lbs., it is an easy matter to deduce a very simple rule for estimating the horsepower of the engine. The following rule is precisely correct

*_Engineering-Contracting_, Sept. 2, 1908.

when the product of the piston speed, by the mean effective pressure by the mechanical efficiency is equal to 1,050; and this is ordinarily the case with contractors' engines having cylinders of 8 ins. or more in diameter.

Rule: To ascertain the horsepower square the bore of the cylinder and divide by four.

Thus, if the engine is 8 x 8, we have a cylinder bore of 8. Hence, squaring 8 we have 64, and dividing by 4 we get 16, which is the horsepower. This is the actual delivered, or brake, horsepower.

For smaller engines, whose piston speeds are usually less, it is safe to divide the square of the bore by five instead of by four. A 6 x 6 engine would, therefore, have 7 horsepower.

If the engine has two cylinders (duplex), of course the horsepower is twice that of a single cylinder.

A boiler is usually estimated to give one horsepower for every 10 sq. ft. of heating surface. Hence the horsepower of a vertical tubular boiler is found thus:

Rule: Divide the total heating surface of the tubes and fire box (expressed in square feet) by ten, and the quotient is the horsepower.

The square foot heating surface of a tube is quickly calculated by multiplying the length of the tube in feet by 0.26 and then multiplying by the outside diameter of the tube in inches. Since tubes are ordinarily 2 ins., the total heating surface of the tubes is found by multiplying the number of tubes by their length in feet by 0.52; or, for all practical purposes, *take half the product of the number of tubes by the length of tube in feet.* To this heating surface of the tubes must be added the heating surface of the firebox, which is ascertained thus: Multiply the circumference of the firebox in feet by its height above the grate in feet and add the square foot area of the lower flue sheet.

The diameter of the firebox or furnace is usually 4 to 5 ins. less than the outside diameter of the boiler. The height of the firebox is usually 2 to 2½ ft.

The amount of coal required for a contracter's boiler is about 6 lbs. per horsepower per hour, or 60 lbs. per horsepower per day of 10 hours. Nearly one gallon of water will be required for each pound of coal. About 2¼ lbs. of dry wood are equal to 1 lb. coal, or 2 cords of wood equal 1 ton of coal.

Cost of Cutting Cord Wood.*—Frequently a contractor must figure on using wood for fuel, in which case it is desirable that he know the cost of cutting and piling cord wood. The following average record relates to work done in the state of Washington under the direction of one of the editors of this journal. The work involved the felling of the trees, which were fir, sawing them into cordwood lengths (4 ft.), splitting and piling. Axmen averaged 2 cords per 10-hour day, but an extra good woodman will readily average 3 cords per day. With wages at $2.50, a cord of wood cost $1.25 ready for hauling.

**Engineering-Contracting*, Oct. 7, 1908.

A cord measures 128 cu. ft., of which about 65% is solid wood, the remaining 35% being the voids or spaces between the sticks. Washington fir when green weighs about 3.5 lbs. per ft. B. M., and about 3.2 lbs. when dry. Hence a cord of green fir weighs about 3,200 lbs., or 1.6 tons, which is a good wagon load on most roads. About 10 cords is the ordinary carload.

The daily papers of Sept. 27 contained an Associated Press dispatch from which we have abstracted the following record of wood chopping on a wager. A Vermont woodsman undertook to cut down, chop up, split and pile 5 cords of basswood between sunrise and sunset. He did it, with nearly an hour and a half to spare, for he had completed his work in 10 hours, and had half a cord of unpiled wood left over. The trees ranged in length from 60 to 70 ft. and were 9 to 13 ins. diameter at the butt. At the end of 4 hrs. and 40 mins. he had felled 18 trees and had chopped and split 3½ cords. It took him about 2 hrs. and 40 mins. to pile the 5 cords.

This record is said to be the best ever made. It is interesting to note that this man's output was about double what is regarded as a good day's work, and, in this respect, the record bears out the generalization that a man can perform on a wager about double the physical work that he is accustomed to do day in and day out.

INDEX.

ADVERTISEMENTS